APTD-0755

PB 203 400

Doc. #1

# COMPUTER MAPPING OF COAL RESERVES BY SULFUR LEVEL: GENERAL DOCUMENTATION

## PART I

LABORATORY FOR COMPUTER GRAPHICS
AND SPATIAL ANALYSIS

Contract No. CPA 70-16
Air Pollution Control Office
Environmental Protection Agency

Harvard Graduate School of Design
Cambridge, Massachusetts
April 1971

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INFORMATION SERVICE
Springfield, Va. 22151

198

**BIBLIOGRAPHIC DATA SHEET**

1. Report No. APTD-0755

2.

3. Recipient's Accession No.

4. Title and Subtitle
Computer Mapping of Coal Reserves by Sulfur Level:
General Documentation - Part I

5. Report Date
April 1971

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Harvard Graduate School of Design
Cambridge, Massachusetts 02138

10. Project/Task/Work Unit No.

11. Contract/Grant No.
CPA 70-16

12. Sponsoring Organization Name and Address
Air Pollution Control Office
Environmental Protection Agency
Research Triangle Park, North Carolina 27711

13. Type of Report & Period Covered

14.

15. Supplementary Notes DISCLAIMER - This report was furnished to the Office of Air Programs by Harvard Graduate School of Design, Cambridge, Massachusetts 02138 in fulfillment of Contract No. CPA 70-16

16. Abstracts

A report is presented of a project which was designed to demonstrate the capabilities of the SYMAP Computer Mapping Program to display the sulfur levels of coal and the quantities of coal available at various sulfur levels. The report presents information in the following sections: SYMAP mapping techniques, GRID and SYMVU techniques, discussion of study area graphics, additional data considerations, and data handling routines.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Computer programs
Mapping
Coal
Reserves
Sulfur
Data processing
Graphic methods

17b. Identifiers/Open-Ended Terms
Computer mapping
SYMAP
GRID
SYMVU

17c. COSATI Field/Group 13B, 9B, 8I

18. Availability Statement Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages ~~272~~ 198

22. Price 3.00 0.95

# COMPUTER MAPPING OF COAL RESERVES BY SULFUR LEVEL

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Details of illustrations in
this document may be better
studied on microfiche

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# PREFACE

The Air Pollution Control Office (APCO) of the Environmental Protection Agency is interested in ways of displaying the quantity of coal available at various sulfur levels. It was felt that computer mapping of the coal data might provide a relatively quick and inexpensive tool.

Data was provided by the Bureau of Mines for study areas in the Appalachian Coal Region and, in particular, in a two county area in Maryland. Values for sulfur content, bed thickness, and quantity of coal were manipulated and mapped using several computer mapping programs available at the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design. Although the work was carried out for these study areas, the main emphasis of the project was on providing a tool with general applicability to coal data anywhere in the United States.

The problems of obtaining sufficient reliable data for mapping cannot be emphasized strongly enough. At first glance it would appear that there is a great deal of coal data available. However, when the data are broken down by type, coal seam, and location, there is actually very little useable information available at the present time for all the types of data needed for a study such as this.

It is felt, and has been stressed throughout, that more meaningful results could have been attained if there had been a more equal distribution of data points and a more equal number of analyses taken at these points. All of us were aware that this might be a problem at the outset of the project and our fears have been substantiated. We hope that pointing this out is the kind of constructive criticism that may prove most helpful in overcoming deficiencies in data acquisition so that more meaningful results may be attained in future work.

Of significant importance, however, is the potential applicability of each of the types of maps produced and their usefulness to APCO as adequate data are made available.

The Study Area Report is divided into three main sections, entitled:

I BACKGROUND
II STUDY AREA FINDINGS
III APPENDICES

The first section covers the problem definition, computer program used, study area selection and data acquisition, and the graphic techniques used. The second section discusses the study areas and data used, and the computer maps produced in some detail. The final section contains the step by step description of the mapping procedures used for the study areas, the references, and the technical aspects of program development.

The Study Area Report does not contain any speculative information as to possible future uses of the techniques nor does it include all the computer program manuals and specifications necessary for application of the technique to other coal data and study areas. These manuals and related information are contained in this volume, entitled General Documentation.

Volume Two: General Documentation is divided into two parts. Part I covers the computer mapping techniques and Part II comprises the computer program manuals.

Part I contains seven sections: introduction, computer mapping programs, SYMAP mapping techniques, GRID and SYMVU techniques, discussion of study area graphics, additional data considerations, and data handling routines. This includes all of the general material necessary to understand the techniques which were developed and tested for the study area, and the means for applying them to other study areas. It should be read in conjunction with the Study Area Report and Part II.

Part II contains eight sections: introduction to SYMAP, preparation of packages, map package electives, user subroutine and advanced uses, programming and systems guide, the SYMVU program, the GRID program, and program modifications. This includes all of the technical material necessary to prepare, interpret, and use the three programs, as well as the program modifications made during the project.

We would like to acknowledge the invaluable support and advice of Russell Flegal, Project Officer, Office of Program Development, Air Pollution Control Office, Environmental Protection Agency, and S.J. Aresco, Coordinator, Energy Data Bank, Bureau of Mines, U.S. Department of the Interior.

We would also like to thank Jerrold G. Thompson, Branch

of Computer Sciences and Engineering, Bureau of Mines, U. S. Department of the Interior, Harry Buckley, Director, Maryland Geological Survey, and William E. Edmunds, Head Coal Geologist, Pennsylvania Bureau of Topographic and Geologic Survey for their assistance.

All unpublished data used in the project were supplied by the Air Pollution Control Office and the Bureau of Mines.

| | |
|---|---|
| Cambridge, Massachusetts<br>April 1971 | John C. Goodrich<br>Project Director and Editor |

# VOLUME TWO
# GENERAL DOCUMENTATION
## PART I

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# I. COMPUTER MAPPING TECHNIQUES

1. Introduction
2. Computer Mapping Programs
3. SYMAP Mapping Techniques
4. GRID and SYMVU Techniques
5. Discussion of Study Area Graphics
6. Additional Data Considerations
7. Data Handling Routines

# 1. INTRODUCTION

This section is designed to give a brief overview of the mapping efforts undertaken for the study areas and the important findings that resulted. As stated in the problem definition, the project was designed to demonstrate the capabilities of the SYMAP Computer Mapping Program to display the sulfur levels of coal and the quantities of coal available at various sulfur levels.

Not all of the objectives of the project could be fully met. We were able to display the sulfur levels of coal for a number of seams at different scales depending upon the study area size. We were also able to display the quantity of coal available for less than 1% sulfur content, but the lack of data prevented us from calculating quantity for the study area with the accuracy hoped for.

The program was demonstrated for specific areas with applicability to coal data anywhere in the United States. However, it is likely that many of the problems of map accuracy and data availability encountered with the study area will be found with other parts of the country in the near future.

The study area selection criteria were somewhat academic in that adequate data were not available for any study area--for all variables concurrently and more than one coal seam. The four-state study area chosen was quite extensive but the scale of the mapping--26" wide maps--resulted in a reduction to 25% of original size for printing in this report and a great deal of lost detail.

The isolines for sulfur content used were almost the same as those initially suggested. However, only a few of these isolines were actually relevant, in many cases. The washability and market price information had to be re-stated in terms of sulfur content versus the expected yield of coal. This did not significantly affect the results, although the relationship of quantity to cost was thereby eliminated from the analysis.

In general, the computer mapping techniques were demonstrated for the study areas, these study areas are representative of data and problems encountered elsewhere, and the techniques can now be applied to other areas of the U.S. where coal data are available, subject to the constraints and accuracy of the required data discussed at length in the study area report.

## 1.1. STUDY AREA FINDINGS

To avoid the use of detailed geological maps at the outset, the computer mapping techniques were first tested for an 84 county four-state area in the Appalachian Coal Region. At this scale readily available data aggregated by towns and counties and uncomplicated estimations of bed outcrop lines could be used to give an overview of the sulfur content of coals in a region. Phase I of the project involved mapping the sulfur content of reserves by counties; Phase II involved mapping reserves by towns.

The maps produced showed that Garrett and Allegany Counties in Maryland have significant deposits of low sulfur coal that were worthy of closer examination. This area appeared to have the best data and was chosen as the detailed study area for Phase III. Stage One of Phase III involved the mapping of reserves by mines, while Stage Two was concerned with the mapping of the washability data.*

Our investigation revealed the following characteristics that made this region in Maryland superior to the other area examined, Clearfield County in Pennsylvania, for the purposes of the detailed study area:

(1) adequate source maps for geological conditions and base map development;

(2) uncomplicated stratigraphic relationships and a relatively small number of seams for mapping; and,

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*The four-state area is referred to as the Appalachian Coal Region (Phase I--by Counties--and Phase II --by towns) in Volume One: Study Area Report. It will usually be referred to herein as the study area, or the four-state study area. Likewise, Allegany and Garrett Counties in Maryland (Phase III) will be referred to as the detailed study area. Figure 1 in Volume One: Study Area Report shows the study area boundaries for Phases I and II and for Phase III.

## 1.2. AREA AND DATA CONSIDERATIONS

The study area was defined by the boundaries of counties in the Bureau of Mines data banks which (1) had data on the sulfur content of coal and (2) were in the area referred to as the Appalachian Region. This study area includes parts of Ohio, Pennsylvania, Maryland, and West Virginia. Two coal seams were chosen for mapping, based on their extent, number of analyses, and variation in sulfur content: the Pittsburgh and the Middle Kittanning.

A base map was developed showing the seam outcrop lines and legends such as state and county boundaries. A map of the Pittsburgh Bed outcrop as of 1938--available from the Bureau of Mines--was used in conjunction with the Report of Investigations series to develop the base map. Similar source maps are not available for the Middle Kittanning Bed or for most other coal seams; this 1938 Pittsburgh map had been produced for a specific application.

To map a large scale area such as the four-state region, one presently has recourse to two approaches:

(1) Determining the outcrop lines from a series of larger scale U.S. or state geological survey maps; this is very time consuming, a good knowledge of the geology is necessary, and the maps are not always available for every portion of the region. This method was not used for the study area, but it is the more logical procedure to use.

(2) Defining the study area by the location of data points rather than by the outcrop lines; for some of the study area mapping the boundary was defined by those locations

within five miles (or ten miles) of each data point or town. Unfortunately, it is not possible with such an approach to know the true extent of a coal seam, and, therefore, of a low sulfur coal deposit.

### 1.2.1. Data Availability and Form

We investigated the form and extent of the data as well as their general availability. We found that for whatever region we selected we could obtain data on sulfur content for raw or clean (washed) samples by county, town, or mine for each coal seam from the Bureau of Mines data banks. We could also obtain data for the number of analyses taken at a mine, or for a town or county as a whole. This form determined the data banks for sulfur content used in the project: number of analyses, low, mode, and high values for sulfur, by counties, towns, or mines.*

For the four-state area the level of detail for mapping was limited to data points at town centers because, if data points at mine locations had been used, the small-scale mapping would have created a large number of superimposed data points that would cancel out the accuracy obtained at the mine level. Even at the town level there were 8 superimposed points at 4 locations for the Pittsburgh Bed and 2 at 1 location for the Middle Kittanning Bed, for raw samples. When a large area is mapped at a small scale and many data points are available, the problem of superimposition can be significant. This problem did not occur for the detailed study area, due to scale and number of data points.

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*No uniform format for washability data had been established at the time of the study area mapping.

For the detailed study area the Upper Freeport and Upper Bakerstown Coal beds were chosen for mapping based on the availability of data and source maps showing the seam outcrop lines. The sulfur content data was available in the same form as with the four-state area. However, bed thickness data were derived from several federal and state sources for the particular seams. The availability of similar data and its extent for other areas could significantly affect the use of the mapping programs to determine the quantity of coal reserves for a region.

Likewise, the base maps showing outcrop lines and areas over 28" thick were developed using several sources, as described in Section III (Appendices) of the Study Area Report. Together, these sources contained sufficient information to adequately determine outlines, but similar reports may not be available for every region. The maps were developed with a great deal of detail so as to extract small areas for closer analysis.

### 1.2.2. Washability and Quantity of Coal

The mapping for the detailed study area was also concerned with washability data and the quantities of coal that might be made available under various mining and economic assumptions. Data handling prior to mapping generated values for both total sulfur content and pyritic sulfur content, given different yields from washing with several screen sizes. The sulfur content that could be attained through washing is the total sulfur content, less all or part of the pyritic sulfur, since the pyritic sulfur is easier to remove than organic sulfur. We do not know what percent of the pyritic sulfur can be removed; therefore, both the total sulfur content and the total less all pyritic sulfur were mapped to represent the two extreme assumptions.

The quantities of coal that could be made available at different yields were determined accordingly. For any study area it will be necessary to calculate the sulfur content at various yields, based on the analyses, and take into account the pyritic sulfur in determining the quantity to be mapped.

For the detailed study area the first task was to determine the yields from washing to be mapped, in light of current mining practices and incremental price increases at the market. The criteria were translated into 50%, 60%, 70%, and 80% yields as being representative of the problem, with the 60% yield being the one of primary interest. The second task was to determine the appropriate sulfur content for these yields, given the sampled and derived relationships from the Bureau of Mines. The values for some of the yields had been statistically derived but values for others were interpolated from plots for the 3/8" and 1 1/2" mesh top size screens.

Quantity was determined as follows: if the sulfur content was less than 1% for any character location on the map, then the quantity would be calculated and mapped as a function of the bed thickness at the location. The algorithm for determining quantity from thickness was obtained from the Bureau of Mines and is discussed in Section III (Appendices) of the Study Area Report. It assumes that there are 1676 tons of coal per acre-foot. Quantity was calculated based upon both total sulfur and total less pyritic sulfur for the total outcrop and for the areas over 28" thick for the Upper Freeport Bed.

### 1.2.3. Types of Maps

From the washability data the sulfur content and thickness data, and the derived quantity, several types of maps were run for the detailed study area:

(1) sulfur content of reserves;

(2) quantity of less than 1% sulfur coal, in the ground;

(3) Composites for sulfur content and quantity, for the Upper Freeport and Upper Bakerstown Beds;

(4) sulfur content of washed data, by yield and top size;

(5) comparison of sulfur content from 3/8" versus 1 1/2" top size;

(6) quantity of less than 1% sulfur coal assuming washing, by yield and top size; and,

(7) comparison of quantity of mineable reserves and washed marketable coal at 60% yield.

The original data--sulfur content, thickness, and washed sulfur content--were mapped by mine and sample locations. Quantity was calculated and mapped by character cells. Only sulfur content for reserves was mapped for the entire four-state area.

### 1.2.4. Conclusions

As expected, the greatest difficulty encountered in the project was the obtaining of adequate data to work with. Sufficient data to produce meaningful results never were available for the detailed study area of Phase III, although this did not significantly detract from the demonstrations of the applicable techniques.

Examination of the graphics produced in Phases I and II has shown that there is a definite need for: (1) a more equal number of analyses at each sampling location, and (2) a more evenly distributed pattern of sampling locations. The latter problem is especially acute in Phase II while the former problem pertains to both phases.

In Phase III it was difficult to draw any statistically sound conclusions. The reliability of the thickness data was very suspect and the spatial interpretation of the washability data limited due to the number of data points; consequently, it was not possible to determine with any accuracy the actual quantity of coal that might be available for this particular study area.

Furthermore, not enough information was known about such parameters as the vertical location of samples in a bed to ensure representative data for mapping. Until sufficient data are available to standardize the samples and remove the effects of parameters other than spatial location, substantive results cannot be obtained, except on a large-scale basis such as Phases I and II.

Although the particular study areas may not be representative of the country as a whole, they could adequately demonstrate the scales of analysis useful to APCO. The larger the scale--given the same ratio of detail to scale--the less constraining are the data point requirements, as shown by the Phase I and Phase II maps. But, at the scale of one or more counties (Phase III), it is necessary to have good data point coverage by mine location.

## 2. COMPUTER MAPPING PROGRAMS

Three computer mapping programs are useful for this work. The SYMAP program can be used for the majority of maps produced, particularly for maps of sulfur content and bed thickness. The GRID program--which was adapted from SYMAP to specifically handle data input in terms of a regular grid--is best used in all cases where maps or data sets are to be compared on a cell by cell basis, as in determining the quantity of coal at various levels of sulfur content. Finally, in a few cases the SYMVU program may be useful to display the three-dimensional representation of the same surface shown in two-dimensions with the SYMAP or GRID programs.

### 2.1. THE SYMAP PROGRAM

SYMAP generates map displays showing the values of spatially distributed data, according to their actual geographic location on a base map. Combinations of standard computer printout symbols are used to print a scale of tone from black to white which can correspond to a data value range from large to small. Mathematical computations can be performed on the data if necessary before mapping. Options are provided for the rescaling of raw data and for variations in symbolism.

For the study areas values for sulfur content, bed thickness, and quantity of coals in tons per acre were displayed for each of several coal seams. Uniform scales of symbolism were used so that maps in a series could easily be compared. In many cases mathematical computations were performed prior to mapping, particularly to determine the quantity of coal available for a given sulfur content, given various yields from washing.

The program can produce conformant, contour, proximal, and dot maps. In conformant maps, predefined areas or zones are filled with the symbol tone assigned to their data values. Contour or isoline maps show the variation of the data over the whole study area; the display is analogous to the contour bands used to show changes of elevation on topographic maps. Proximal maps use the nearest-neighbor principle, with any non-data position being given the value of its nearest data point. They are similar in appearance to conformant maps. The program will also produce dot maps, using a variety of symbols. The maps produced for the study areas were all of the isoline or contour type. This was because it was felt that the data being mapped--sulfur content, thickness, and quantity--all tend to vary continuously over a coal bed rather than to exhibit fixed values for data zones.

To produce computer maps, a deck of punched cards must be prepared as input to the computer. This deck consists of a number of "packages," each covering a specific category of information. The most basic of these packages, with a brief explanation of their general purpose, are listed below. The MAP package is always required; use of the other packages is determined by the type of map desired.

The MAP package specifies, below the map, an appropriate title for the identification of each separate map that is to be run. It then instructs the computer to make each map by using certain electives that may be useful. It is not necessary to specify any of these electives since each has a standard default. The availability of these electives is a major feature of the SYMAP program and adds greatly to its flexibility. Some of the electives are:

(i) Size: used to specify the overall dimensions of the rectangular border surrounding the study area on the output map;

(ii) Content: used to specify the portion or extent of the study area (as shown on the source map) to be mapped by the computer; the scale of the map to be produced can be changed, or a portion of the study area may be shown, at any scale.

(iii) Number of Levels: used to specify the number of levels, or class intervals, (up to twelve) into which the total range of the data is to be subdivided for mapping purposes; another elective can be used to specify the value range intervals for these levels;

(iv) Symbolism: used to specify the black-to-white tone symbolism for the levels as well as symbolism for the data point locations, contour lines, and areas outside the study area; and,

(v) Text: used to provide supplementary textual information below the map.

The OUTLINE package is used to describe the outline of the study area by specifying the x-y coordinate locations of the outline vertices. For the study areas the outline was generally the seam outcrop line or the line of 28" bed thickness.

The DATA POINTS package is used to give the positions of the data points to which data are to be related, by specifying their coordinate locations. Data points may be either points for which data are available or centers of areas ("data zones") for which data are available. For the study areas the data points were the centers of counties or towns for which data on sulfur content were known or the actual or assumed location of mines, mine openings, or core samples.

The LEGENDS or OTOLEGENDS package causes supplementary information to appear on the face of the map by specifying coordinate locations and content. Legends include such things as political boundaries, location names, a scale and north arrow, and the title block. The principal legends used for the study area were state and county boundaries, relevant place names, and the scale. It may be appropriate to use an overlay for some of the legends.

These three packages--OUTLINE, DATA POINTS, and OTOLEGENDS are used (together with a MAP package which is always required) to produce a 'base map' for testing purposes. The base map and consequently these packages generally remain the same for a whole series of maps. Once the base map has been determined and tested it is necessary to relate the appropriate values to the data points--by use of the VALUES package--and select any options desired, together with the title, for use in the MAP package.

The VALUES package is used to assign the appropriate values to the data points. For the study areas in one case the values for sulfur content (averaged for all samples in a county for the seam in question) were assigned to the centroid of the counties which had been chosen as the data point locations. Very often a series of maps is to be run from a large data bank of variables. In this case an extremely flexible user-subroutine is employed to read in the variable to be mapped. Raw data given to the computer may be related, manipulated, weighted, and aggregated in nearly any manner desired with this subroutine to produce the values for mapping. The subroutine may also be used in conjunction with the other packages, often to transform coordinate locations.

Immediately ahead of the packages of data cards described above, certain introductory cards (as required by the particular computing center being used) must be provided--together with a copy of the SYMAP program on cards, tape, or disk.

## 2.2. THE GRID PROGRAM

The GRID program is a modified version of SYMAP specifically designed for displaying data collected on the basis of geographic grid cells. Each grid cell may be shown on the computer-produced map as a single character or group of characters. Whereas SYMAP accepts information at irregularly spaced data points such as mine locations, and then interpolates values at all points on an assumed surface, the GRID program requires that a value be read in for every grid cell. These values are then displayed directly without interpolation.

The GRID program was used for the detailed study area to determine quantity of coal at each grid cell mapped (where the sulfur content was less than 1%) based on the previously mapped values for bed thickness interpolated from data points with the SYMAP program. The program was also used to produce composite maps of quantity of coal for more than one bed; here the quantity for each of the beds was summed at each of the grid cell locations. In each case the data points--each grid cell--and the values were provided from the SYMAP program runs.

To obtain a map, the user must provide three sets of instructions and has the option of providing a fourth set.

The instructions are prepared in the following packages: Data Package (usually a separate tape), Map Package, Irregular Outlines Package (Optional), and Subroutine Flexin.

The DATA package contains the data which generates the graphic display. It is similar to the VALUES package in SYMAP. The program is written for a maximum of 10,000 grid cells, but the Multiple Data Set Option permits the user to handle unlimited numbers of data cells. For the study area approximately 12,000 grid cells were used. These were displayed as single character cells allowing for direct comparability between the SYMAP-produced maps and the GRID-produced maps derived from them.

The MAP package permits the user to specify the precise form of the map output in terms of various electives. It is similar to the MAP package in SYMAP; many of the electives are specified with exactly the same format.

The IRREGULAR OUTLINE package allows the user to specify the boundaries of the study area when he is not dealing with a grid which is rectangularly bounded. For the study area the same outline was specified as was used with the SYMAP program.

Legends are handled differently with this version of the program. A special edited version of the SYMAP program is used to create a data file containing the legends. The GRID program then automatically reads these legends in; therefore, the same legends can be used with maps produced by either program. The necessary program changes are contained in Part II, Computer Program Manuals.

SUBROUTINE FLEXIN is the Fortran subroutine which allows the user to specify the format of the data. It is identical in use to the user subroutine of SYMAP; however, with the GRID program the subroutine must always be used to specify the format for reading in the values. For the study area values created by the SYMAP program were read in, compared or manipulated, and resultant values mapped on a cell by cell basis.

## 2.3. THE SYMVU PROGRAM

The SYMVU program provides the user with oblique views of a given surface. The user of SYMVU needs to supply a matrix of surface values, and a set of parameters specifying the type of oblique view desired. Both SYMAP and GRID can generate the necessary matrix values directly. For the study areas SYMVU s were produced for surfaces mapped with SYMAP, using the stored matrix of values.

Some of the basic options available to the user are:

(i) the oblique view may be orthographic or in perspective;

(ii) the viewing angle may be varied in both the vertical (z) direction and horizontal (x, y) plane;

(iii) the lines that SYMVU generates to define the surface of the three-dimensional view may follow down the columns, across the rows, or through the diagonals of the input matrix;

(iv) the size is specified by width and height;

(v) treatment of the non-study area may consist of deleting it, darkening it, or setting it to a value of zero.

## 2.4. MACHINE REQUIREMENTS AND OUTPUT DEVICES

The SYMAP program is written in Fortran IV. It can be used on a computer system equivalent to the IBM 360-40, or CDC3600. Computer storage requirements are at least 32,000 words, or 128,000 bytes. Such systems are available in most commercial, government, and university computation centers. All of the discussions herein assume the use of Fortran IV on an IBM 360-65 at the Harvard Computing Center, as well as version 5.15 of the SYMAP program which requires 150K bytes of storage. Certain operations--comparing surfaces using a newly-written subroutine for SYMAP--require 200K bytes.

The GRID program presently operates on an IBM 360/40. Version 3 of the program was used for the study area and the manuals correspond to this version. It was run on an IBM 360-65 at the Harvard Computing Center and required 150K bytes of storage.

The SYMVU program will also operate on an IBM 360/40. Version 1.0 of SYMVU was used for the study area and the manuals correspond to this version. It was run on an IBM 360-65 at the Harvard Computing Center and required 200K bytes of storage.

The maps produced by either the SYMAP or GRID program are generated by a standard chain line printer. The printer used for the study area maps was an IBM 1403 at the Harvard Computing Center. The printer is capable of producing 132 characters on a line; at 10 characters per inch, this means a map 13 inches wide, with two characters for the vertical borders. The printer produces eight lines per inch with these mapping programs.

If a map is too large to fit on one sheet of paper, the SYMAP program will subdivide a map into 13 inch sections. Since this is frequently the case, a simple splicing job is required. The GRID program has a similar option for producing as many map sheets as are required; generally each map sheet is associated with a separate data set. With these programs a special carriage control tape is used to assure the proper line spacing for each page; in this way the normal spacing at the top of a page does not occur in the middle of a map. The programs allow one to print up to four overprinted characters to achieve the desired gray scale for mapping.

The three-dimensional views produced by the SYMVU program are generated by a pen plotter. The plotter used for the study area displays was an 11 inch CALCOMP plotter at the Harvard Computing Center. The vertical size of the plot is governed by the height of the paper (maximum of 10 inches); there is no constraint on the length of the plot because the paper is on a continuous spool.

## 3. SYMAP MAPPING TECHNIQUES

As stated in the section on computer mapping programs a deck of punched cards must be prepared to produce computer maps. This deck will consist of certain introductory cards (job control language and a subroutine) and a number of data "packages" each composed of additional cards covering a specific category of information about the map or maps to be produced.

The number of packages used depends, exclusively, on the user. For the study area a total of 6 packages were set up for SYMAP input:

1. A-OUTLINE--used to describe the boundary of the coal bed by specifying the x-y coordinate locations of the outline vertices.
2. C-LEGENDS--used to describe the locations of and specification for certain text, such as the graphic scale and legend box. These legends do not change size with scale changes in the map produced.*
3. C-OTOLEGENDS--used to describe the location of point, line, or area legends such as political boundaries. This package adjusts with scale as does the A-OUTLINE package, and with only minor alterations in card order one package can easily be converted to the other. For the study area the C-OTOLEGENDS package contained the significant state and outside county boundaries for the four-state region.

These three packages were used to produce a base map, together with the appropriate data points packages and a map package which is always required.

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*This package has been made obsolete by the C-OTOLEGENDS package which can take into account scale changes. Manual Specification for this package will be found in Part 2 under Program Modifications, not Preparation of Packages.

4. B-DATA POINTS--used to describe the locations of points for which values are available, by specifying the x-y coordinates. These locations may be either actual points, such as the mines in Phase III and towns in Phase II, or the centers of areas, such as the counties in Phase I.

5. E-VALUES--used to describe the values to be assigned to the appropriate data points. These values were sulfur content by county, town, or mine and bed thickness by mine for the study area.

These two packages, together with the user subroutine, were used to access the data banks and provide the information to be mapped.

6. F-MAP--used to describe the map title and various electives controlling the extent and nature of the map to be printed.

The following sections discuss the base map preparation (A-OUTLINE, C-LEGENDS, and C-OTOLEGENDS), data preparation (B-DATA POINTS and E-VALUES), user subroutine, map package (F-MAP), and data handling considerations for producing series of maps.

## 3.1. BASE MAP PREPARATION

In preparing a base map the following procedures should be followed: (i) select and obtain appropriate source maps, (ii) determine and code outlines and legends, and (iii) test the base map with and without data point locations.

### 3.1.1. Source Maps

The first step in producing a computer map is to obtain a source map of the study area. The map must be prepared in a form that is "readable" by the computer. The base map should show such information as political boundaries (for reference), coal seam outlines, identifiable water bodies and other pertinent information. It should be descriptive but not cluttered.

The choice of a map scale becomes important if enlargement of promising areas is desired. Therefore, the source map should be of the same size or larger than the desired output map. Since the Bureau of Mines data are located by UTM coordinates, the Army Map Service series is a wise choice. If the 1:250,000 series is used, it will probably be necessary to use more than one sheet to complete the source map for areas such as the four-state region.

If the study area exceeds more than one UTM zone, one would be wise to employ another projection unless one chooses to solve the problem mathematically. Our work for the study areas was greatly facilitated because the data were restricted to one UTM zone.

For this beginning stage in the project a base map at a scale of 1:250,000 was prepared from the Army Map Service series of the same scale. This particular series was chosen because of availability and scale. By using this scale the detail is presented in reduction and it is possible to select portions of the map to blow up for close examination (see maps D-3 thru D-7). These maps also have Universal Transverse

Mercator grids (UTMs) marked on the map. This became an important factor for Phases II and III since all of the data are located by UTM coordinates.

A base map overlay was prepared by tracing 84 conterminous county outlines, in sections, onto the working base map which was 69.7" by 77.7" (x-y coordinates). The data points for the raw and washed values for the Pittsburgh Bed were placed in their respective counties. Delineation of the outer edge (the outline of the four state and county area) and state lines was made on this map.

In many cases, it will be necessary to superimpose an outline onto the traced base map which contains all of the political reference features. Such is the case when a coal seam is to be delineated since it is infrequent that all maps needed will be of the same scale. From experience, the best method to follow is to photo-enlarge one of the maps so as to arrive at a compatible scale. This procedure will yield faster, cheaper, and more accurate results than any hand method, such as similar squares.

The Bureau of Mines provided us with a base map of the Pittsburgh Coal Bed at a scale of 1:506,880 or 1 inch = 8 miles. It was almost exactly half the scale of the base map we had been using. However, because of incompatibility in map projection between the base map at a scale of 1:250,000 and the 1:506,880 map it did not seem feasible at the time to photo-enlarge the map by a factor of two. Therefore, the map of the Pittsburgh Coal Bed was enlarged by eye to the scale of the 1:250,000 base map. In retrospect, it would have been much less time consuming and more accurate to have photoenlarged the map, since the error factor would have been less in the photo-enlargement than in the enlargement by eye.

For the detailed study area maps were obtained from the state Geological Service at a scale of 1 to 62,500 or approximately 1" = 1 mile. Some of these maps show the outcrop line of each of the coal seams existing in the area, along with symbols keyed to the names of the various beds.

A second series of maps at 1" = 2 miles was obtained showing various outcrops and mineable reserves in the coal seams. This was a series of maps that had been prepared by a consultant. They show well-defined outlines for the strip and deep coal reserves, including the deep reserve limit for the Upper Bakerstown and the Upper Freeport seams. They also show the portion of each seam greater than 28" thick.

The consultant maps were enlarged and the information from them transferred to a composite map at a scale of 1" = 1 mile. In this way information on the state maps (also at 1" = 1 mile) could be used and the scale of the base map would be such that portions could be enlarged without losing detail on the final computer maps.

The enlarging was done using the similiar grid technique. This process consisted of producing gridded overlays for both the small map (1" = 2 miles) and the large map (1" = 1 mile). These overlays were directly proportional to the scale differences between the two source maps. Using the horizontal and vertical lines of the grids, the outline was transfered quite easily from one scale to the other. Likewise, information was taken from the larger scale so as to produce composite overlay outlines for the Upper Freeport and Upper Bakerstown coal seams. Periodic adjustments had to be made so that the information would conform to the general outlines of the county geological maps.

A separate overlay was produced for each of the following:

--1. Upper Freeport total outcrop;
--2. Upper Freeport area over 28" thick;
--3. Upper Bakerstown total outcrop;
--4. Upper Bakerstown area over 28" thick.

These four overlays served as the source maps for developing the computer base map outline packages.

If source maps are available for a region which contain all pertinent information at the same scale, many of the preceeding procedures can be eliminated.

### 3.1.2. Outline Packages

In coding the outline package the study area boundary is approximated by a series of straight lines connecting adjacent points. These points should be numbered for reference. The data points and legends should also be referenced in a similar fashion. The number of outline points is completely arbitrary - the greater the number, the greater the accuracy in approximating the shape. One may start at any point on the outline and proceed in either direction.

In measuring a great number of points by hand the chance for human error is increased. It is recommended, therefore, to use an electronic digitizer. The digitizer is able to quickly and accurately produce a great number of coordinates in card form. The procedure involved in using this machine is quite simple.

The user tapes the base map to the table in such a way that the x and y axes on the map are true to the horizontal and vertical, respectively. The origin is then set by the user to 0,0 in the top lefthand corner of the map; the machine can be instructed to measure the coordinates in inches or any other units desired. The coordinates are punched on cards by lining up the cross-hairs on an adjustable arm over the point that one wishes to digitize and then pressing a button on the arm. The keypunch machine is interfaced to the digitizer. The x-y coordinates are punched in inches (or UTMs) to two decimal places in columns 11-20 and 21-30 and a reference number is punched in a third field. Numbers are assigned to these column fields by the use of a drum card in the keypunch machine. The resultant card output is in a format compatible with the SYMAP input, with only minor alterations involving the regrouping of cards.

For smaller areas with fewer vertices, the coding is done by hand with a ruler. It makes no difference what measurement units are used.*

The SYMAP program will not accept an outline that has an excess of a hundred vertices in the A-OUTLINE package. Since most study areas are defined by at least a couple hundred such vertices, it is necessary to break up the cards into "islands" or sections of 100 vertices or less. In so doing, the appearance of the map is not affected.

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*For accurate row and column placements the Laboratory had developed a special SYMAP ruler which has 10 units per inch horizontally and 8 units per inch vartically. This corresponds to the respective number of columns and rows per inch of map output.

After the outline of the Pittsburgh Bed had been punched onto cards using the digitizer, it was then grouped into 71 different "islands". Each island represented one outcrop, or part of an outcrop, in the case of the major seams of the Pittsburgh Bed.

It is wise to make a couple of test maps (or base maps) before any data are used. This is done as a safeguard against any errors which may have been incurred as a result of a digitizer malfunction or a mixup in card order. Because of the sensitive and delicate nature of the digitizer, it tends to be prone to errors. These errors, however, are very easily discovered upon running the first base map. From the nearly 2000 cards created for the study area outlines, about 200 (or 10%) had validity checks because of a defunct transistor in the machine. This kind of error produces a multiple punch on the card which is unacceptable to the card reader. The mistake however, is easily correctable.

The Phase I base map, including the seam outcrop, was made with a great deal of detail so that particular sections could be 'blown up' for closer examination in Phase II. It was felt that this feature of the technique would have special usefulness to APCO and the Bureau of Mines. For the seam mapped a detailed outline of 500-1000 points was required to achieve this accuracy at the enlarged scale. The outcrop used for the Pittsburgh seam was the 1938 strippable reserves.

For the detailed study area the outline was coded by hand. This procedure involved the use of special graph paper with the x-y coordinates printed along one side and the top. The source map overlay was placed on top of the graph paper and the coordinates for each point were written on coding forms, proceeding from point to point in a clockwise manner, and repeating the starting point to 'close the outline'. This information was then punched onto cards--one pair of coordinates per card. Each island was a separate deck with the decks for all islands forming the A-OUTLINE package. These packages were prepared separately for each of the four computer base maps.

Each of the base maps was run and any discrepancies with the source maps were noted and corrected. For instance, when the Upper Freeport total outcrop base map was tested together with the data point locations, it was found that the data point locations all fell in the two main islands. No data points existed for the island which was in the upper left hand corner of the study area as well as for the small islands on the westernmost side of the study area. It was felt that any information interpolated from the data points to these islands would be invalid and misleading. Therefore, these islands were removed from the outline package.

The size of the area for mapping in Stage Two for the Upper Freeport Bed was determined by the location of the values for washability. This area was defined for mapping by changing Elective 2 in SYMAP. No changes in the A-OUTLINE packages were necessary to produce maps at this scale and for this area.

### 3.1.3. Legend Packages

The number and complexity of legends to be shown on the map is completely at the discretion of the user. Some people prepare elaborate computer-printed legends, whereas others show nearly all legends on hand-drawn overlays. The computer program manuals discuss the use of and specifications for point, line, and area legends in some detail.

Line legends such as rivers, bridges, roads, and county or state lines which must be adjusted if the scale of the map is changed are put into the C-OTOLEGENDS package. Appropriate deletions or additions to the line segments are made in accordance with change in scale. In both Phases I and II the C-OTOLEGENDS package contained the significant state and outside county boundaries of the four-state region.

For the study area certain supplementary information was put into the C-LEGENDS package. This included the graphic scale, legend box, and all the state names. Unlike line legends, these will _not_ adjust in scale and therefore must be specified in terms of _output_ units (rows and columns). Like C-OTOLEGENDS the coordinate locations and content are specified. The same C-OTOLEGENDS package was used for all maps in Phases I and II. The C-LEGENDS package was changed for Map Series D.

For the detailed study area of Phase III four separate legend packages were developed, two for each stage of the mapping. The C-OTOLEGENDS package for each stage contained identical information, but the C-LEGENDS packages differed according to the scale of the output map. The information provided in each of the C-OTOLEGENDS packages consisted of the state outline showing the border between Maryland and

West Virginia and the county border separating Allegany and Garrett Counties. In the C-LEGENDS packages point legends were used for names, the legend block explaining the symbolism used to delineate county and state outlines, and the graphic scale.

The coordinates of the various outlines were located on the source map in the same manner as for the outline packages. Slight adjustments were made to produce a high quality, single character line defining the state and county boundaries. This was necessitated by the reduction in size from the original scale of the source map to the size of the final computer map; a clustering of symbols occured because of the reduction in size.

To eliminate this problem the x-y coordinates for the points to be removed were recorded from the output map; a blank symbol was assigned to each of these points, in effect removing the unwanted symbols. These blank symbols were coded as a part of each of the C-LEGENDS packages, but their effect was to override instructions specified in the C-OTOLEGENDS package. This allowed us to develop a pleasing and graphically consistent legend. Operationally, it would be easier to code legends from a source map in one step, taking into account the reduction in size to the final maps. With the exception of the blank symbols the uses of the C-LEGENDS and C-OTOLEGENDS packages were the same as in Phases I and II.

## 3.2. DATA PREPARATION

Two separate packages are prepared with SYMAP to input the data: the data points and the values packages. The values are often in the form of a data bank--several variables per record, rather than the one variable coded under the standard SYMAP procedure. Subroutine FLEXIN is then used to access this data bank.

### 3.2.1. Data Points Package

For mapping it is necessary to locate each county, town, or mine by some kind of an x-y coordinate system. SYMAP will accept any unit of measurement as long as one specifies to the program what measurement system is being used. The program expects coordinates to increase in magnitude in both the horizontal and vertical directions, unlike UTMs which increase in magnitude in the horizontal but decrease in the vertical direction. This incompatibility can be overcome in Subroutine FLEXIN. If coordinates such as UTMs are read into the program and not changed, then the resultant map will appear true in the horizontal but upside down in the vertical direction.

Locating data points can be complicated although the coding is done in a similar way to the outlines package, using a digitizer if the number of points warrants its use. For the study area one data point was assigned to represent an entire county.

As in the case of the outline of the Pittsburgh Bed, the coordinates for the data points were digitized in inches. The rationale for the placement was two-fold:

1. If a map from the Report of Investigation series was available, the point was placed at the center of gravity of the reserves in seams of 28" or more in thickness;

2. If no map existed, then the point was determined by using the center of gravity of the existing Pittsburgh seam for that county based on the 1938 map of 1:506,880 scale.*

All vertical coordinates were punched as a decimal number in columns 11-15 and all horizontal coordinates were punched as a decimal number in columns 21-25. Columns 50-80 were used for a reference code for this package and the E-VALUES package.

In locating the town data points for Phase II the first step involved removing those towns from the data listing which were not in the 84 county study area. This kind of initial checking of data is much more important with computer _mapping_ than with established computer _tabular_ analysis. In a number of cases, the same town appeared more than once for the same bed and the data had to be aggregated. This procedure was necessary because SYMAP can only associate _one_ value per data point location.

The mine data was aggregated to the nearest town. This was done because the small-scale mapping would create a great number of superimposed data points that would negate the effort expended in doing a map of such detail at the scale selected. Even at the town level, there were superimposed data points. The character symbol, slash (/), was used to represent this phenomenon on the map for the study area. This character symbol can be specified by the user in elective 7 of the MAP package.

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*These sources of information are described in _Volume One: Study Area Report._

UTM measurements were used since the coal data at the Bureau of Mines are located by these units for the United States. This is in contrast to the outlines, legends, and county data points which were measured on the source map in inches. Subroutine FLEXIN was used to convert the UTMs to inches so that all units would be compatible.

The procedure for locating the 200 plus towns involved using three different map scales. Before any towns could be located, it was necessary to devise a standardized system for the easy removal of coordinates. A 10x10 kilometer acetate grid overlay was created for this purpose.

As many towns as possible were located using the grid overlay on the Army Map Service 1:250,000 series. All towns are situated within UTM Zone 17 of this series. Approximately one tenth of the towns could not be found because of their small size. It was therefore necessary to use USGS maps of a larger scale--namely the 1:62,500 and 1:24,000 map series. The towns were located within a county by using the the 1968 Rand McNally Commercial Atlas and Marketing Guide and then on large scale quadrant maps at the two aforementioned scales. Points representing the towns were located on the 1:250,000 maps by a combination of two methods: (1) accurate latitude and longitude and (2) visual comparison by identifiable physiographic features for further locational accuracy. The UTM coordinates were then easily coded from the map by using the acetate grid.

All UTM coordinates were read to the nearest one kilometer cell. Decisions had to be made concerning two types of locational problems: (1) if a town was larger than one UTM cell, then the cell nearest to the central business district was used and (2) if a small town (shown by a dot on the map) fell on either the horizontal or vertical line or both, then the cell nearest to a mine symbol was used.

Since all the towns were within one UTM zone it was only necessary to record the last three UTM numbers onto the cards. All of the data points were sorted by machine in ascending order by their x and y coordinates as a verification in keypunching, and in the locational accuracy of the towns. It is a much simpler task to recheck the town locations on the map quadrangles if they are grouped by UTMs. By sorting on both the x and y column field, one sorted listing provides a cross-check for the other. Since each card has a uniquely associated point sequence number, they may be sorted back into the proper order if dropped out of sequence.

For the detailed study area all of the data points for both beds and for sulfur content, bed thickness, and washability were coded in terms of UTM coordinates. The coordinates corresponded to mine or sample locations.

A separate B-DATA POINTS package (and corresponding E-VALUES package) was prepared for each computer run. This consisted of a separate card for each data point to be mapped. On each card the UTM coordinates of the point, a reference number, and a code related to the mine or sample location were punched.

There were superimposed data points for the sulfur content values for both seams. For the thickness and washability information, there were no superimposed data points. A superimposed data point corresponding to a top bench value was removed from the washability data bank; the common data base of the values should be carefully checked before the data banks are prepared.

The SYMAP program handles superimposed data points by summing and calculating a mean for all values that are located at the same point; thus, a new value is calculated for use in the interpolation procedures. Taking the mean of two values that are themselves modal values based on different numbers of analyses may well skew the results; superimposed data points for such data should, therefore, be avoided.

### 3.2.2. Values Package

The values should be punched onto cards to create a data bank. A data bank, as used here, is a card deck (or, tape or disk file) in which each record contains a unique location and the values for all the variables associated with it. This information may be stored in any convenient format. Since each record contains more information than is applicable to any given map, the appropriate variable can be mapped by using Subroutine FLEXIN. The values and data points must be in a 1:1 correspondence. Therefore, whereever data points are removed from the original information, the values must also be removed.

For the study area the cards were punched in a format for easy identification as follows for the town data:

Number of Analyses,
Low Sulfur Value,
Mode Value,

High Value,
Bed Code,
Raw or Washed,
Point Sequence Number,
Three-Digit State Code,
Three-Digit County Code,
Five-Digit Town Code, and
Town Name.

The majority of the towns had more than one mine (value) associated with them. It was necessary to arrive at one value per town by the following procedure:

| Value | Procedure Adopted |
|---|---|
| Number of Analyses | Mathematically totalled by town |
| Low Sulfur Value | The lowest sample taken was used for the low value. |
| Mode Sulfur Value | The most frequent or the mode value was used |
| High Sulfur Value | The highest of the high values was used. |

### 3.2.3. Use of Statistical Routines

The data for each variable to be mapped were run thru a small statistical computer program called SPSS (Statistical Package for the Social Sciences*).
This package program can compute the mean, median, mode, variance, standard deviation, skewness, range, minimum and maximum of the data. It can be used to generate a frequency distribution of the data values to aid in the choosing of contour intervals for mapping.

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*See Nie, Norman, et al.; SPSS, Statistical Package for the Social Sciences, McGraw Hill, 1970

Too often the user of SYMAP does not know the frequency distribution of the data to be mapped; consequently several test maps are made before the optimum value range intervals are determined for the final maps. By using a statistical program such as SPSS to determine the value range intervals, considerable time and money can be saved.

For the study area it was decided that equal value range intervals would be used for all maps. For any study area where a large volume of data is to be mapped and several value ranges exist, a program such as SPSS used prior to mapping may prove very useful and time saving. The number of data points for mapping in Phase III did not warrant the use of SPSS to determine frequency distributions.

## 3.3. SUBROUTINE FLEXIN WITH SYMAP

The input deck consists of a few introductory cards which preceed the various packages. A number of these cards form a user-subroutine called by SYMAP which is known as Subroutine FLEXIN, written in FORTRAN IV. The user, commensurate with his programming ability, has considerable flexibility in the kind of data transformation he can perform with this subroutine.

Even if no data or program manipulations are desired, Subroutine FLEXIN must be provided in a "dummy" form since it is an integral part of the SYMAP deck. The dummy FLEXIN consists of the following three cards: (1) SUBROUTINE FLEXIN (IFORM, T, FIRST) (2) RETURN (3) END. These cards tell the computer that there are no special manipulations to take place, and, therefore, that all packages are in the standard formats read by the SYMAP program.

For the study area, the instructions required to retrieve the data from the E-VALUES package were placed in this subroutine. Since the values package is essentially a data bank, instructions must be provided to obtain the data pertinent to each map.

Besides being able to retrieve and manipulate data from a data bank, this subroutine can adjust incompatible coordinate measurements for the outline, data points or legends. For example, if the outline and legends packages are in map inches and the data points are in UTMs, then the number of UTMs per inch is specified in the subroutine and the UTMs are converted into map inches.

A single Subroutine FLEXIN was used for the study area for Phases I and II, as shown in Figure 1. The arguments, or variables, transferred to the Subroutine are IFORM, T, and FIRST. "IFORM" is specified in each package to be manipulated by the subroutine; the assigned GO TO statement determines what statement number the program will jump to depending upon the value for IFORM, as follows:

| Package | IFORM | Statement No |
|---|---|---|
| Values | 1 | 10 |
| Values | 2 | 20 |
| Values | 3 | 30 |
| Values | 4 | 40 |
| Values | 5 | 50 |
| Values | 6 | 60 |
| Values | 7 | 70 |
| Values | 8 | 80 |
| Data Points | 9 | 90 |

"T" is the variable name used for returning data to the main program; for IFORM 1 thru 8 T returns the value to be mapped, one data point at a time. For IFORM 9 T is dimensioned and T(1) and T(2) return the y and x coordinates, respectively, for each point.

```
      SUBROUTINE FLEXIN (IFORM,T,FIRST)
      DIMENSION T(3)
      GO TO (10,20,30,40,50,60,70,80,90),IFORM
   10 READ (5,100) T
  100 FORMAT (F5.0,67X,2A4)
      RETURN
   20 READ (5,200) T
  200 FORMAT (5X,F5.1,62X,2A4)
      RETURN
   30 READ (5,300) T
  300 FORMAT (10X,F5.1,57X,2A4)
      RETURN
   40 READ (5,400) T
  400 FORMAT (15X,F5.1,52X,2A4)
      RETURN
   50 READ (5,500) T
  500 FORMAT (F5.0,67X,2A4)
      RETURN
   60 READ (5,600) T
  600 FORMAT (5X,F5.1,62X,2A4)
      RETURN
   70 READ (5,700) T
  700 FORMAT (10X,F5.1,57X,2A4)
      RETURN
   80 READ (5,800) T
  800 FORMAT (15X,F5.1,52X,2A4)
      RETURN
   90 READ (5,900) T(1),T(2)
  900 FORMAT (10X,2F10.2)
      T(1)=(626.-T(1))/6.37
      T(2)=(T(2)-322.)/6.37
      RETURN
      END
```

FIGURE 1
Subroutine FLEXIN with SYMAP

As shown in Figure 1 there are nine different READ statements, or one READ statement for each package manipulated. In this case the data to be read in are on cards for each package. READ statements 20, 30 and 40 produced the values for maps A-2, A-3, and A-4 and READ statements 60, 70 and 80 for maps A-6, A-7, and A-8. READ statements 10 and 50 were not used since a separate subroutine was created to produce the base maps for the raw and washed data for both phases. READ statement 90 was used to manipulate the UTM coordinates into map inches in Phase II. For any one series of maps not all of the READ statements need be used; the packages provided and the corresponding IFORM values will govern what executions are actually performed.

For example Subroutine FLEXIN was used as follows in Phase I. If one wished to produce a map of raw sulfur content (low value), then it was necessary to punch the value for IFORM, 2, in column 5 and the number 33 in columns 9 and 10 of the second card in the E-VALUES package. This first number, 2, caused the second execution in FLEXIN to be performed, starting with statement 20. The FORMAT statement which follows tells the program which columns to read in order to get the pertinent values to be used in the map and to print-out the name of the county which is punched in columns 73 through 80*. The second number on the card in the E-VALUES package, 33, refers to the number of subsequent cards to be read--the number of counties on file. The subroutine was therefore called by the main program 33 times and 33 values for T were returned to the main program.

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*In practice T is dimensioned here: T(1) is the value, and T(2) and T(3) are alphanumeric county names.

In Phase II the data points were manipulated by specifying IFORM 9 in the B-DATA POINTS package. In READ statement 90 the vertical--T(1)--and horizontal--T(2)--UTM coordinates were read in from the cards in the B-DATA POINTS package. The difference between these coordinates and the recorded UTMs at the 0,0 origin (626,322) was then divided by the number of UTMs per linear base map inch. These transformed coordinates were in inches and compatible as SYMAP input. The resultant town placement was accurate to within one and a half miles.

FLEXIN was used in the SYMAP program for the detailed study area to:

1. read in the data points and convert them from UTM coordinates to source map inches. The algorithms following READ Statement 1 in Figure 2 show the conversion made for both Stage One and Stage Two; and,

2. read in all the values for the variables in the appropriate data bank; these values were written out onto a scratch disk file (unit 11); for each map in a run, the file was rewound and read and the appropriate variable was returned to the main program for mapping.

This form of FLEXIN was used for maps E-2 thru E-4, E-6 thru E-8, E-9 thru E-11, F-1 and F-2, G-2 thru G-5, and G-8 thru G-10.

There are several major differences between this and the Phase I and II FLEXIN.* A third argument transferred to the subroutine, first, is used. FIRST is a logical variable used to rewind a tape or disk file on the first call to the subroutine;

---

*Also see Subroutine FLEXIN used with GRID in the next section for more advanced uses of the subroutine and a more detailed explanation.

```
      SUBROUTINE FLEXIN(IFORM,T,FIRST)
      DIMENSION T(3),S(4)
      LOGICAL FIRST
      GO TO (1,10,20,30),IFORM
    1 READ (5,900) T(1),T(2)
  900 FORMAT (10X,2F10.2)
      T(1)=(3986.-T(1))/16.0428
      T(2)=(T(2)-6285.)/16.0428
      RETURN
   10 IF(FIRST) REWIND 11
      READ (5,100) S,T(2),T(3)
  100 FORMAT (4F5.0,52X,2A4)
      WRITE (11,101) S,T(2),T(3)
  101 FORMAT (4F5.1,2A4)
      T(1)=S(2)
      RETURN
   20 IF (FIRST) REWIND 11
      READ (11,200) T
  200 FORMAT (10X,F5.1,5X,2A4)
      RETURN
   30 IF (FIRST) REWIND 11
      READ (11,300) T
  300 FORMAT (15X,F5.1,2A4)
      RETURN
      END
```

FIGURE 2
Subroutine FLEXIN with SYMAP:
Detailed Study Area

in this way data will always be read starting at the beginning of the file.

The variable S is used to read in the values for the four maps from the data bank. Then, depending upon IFORM, T is set equal to one of the four values for S for each data point. For the first map (statement number 10, and IFORM 2) all the values are read from cards and written onto a disk file (unit 11). For subsequent maps the data are read from the file. Therefore, a card deck of values has to be provided only for the first E-VALUES package.

## 3.4. MAP PACKAGE WITH SYMAP

The F-MAP package is the instruction and execution package of the SYMAP program. Normally, only the first 10 map electives are used.*

The use of electives 1 and 2 allows the user to choose which portion of the map he desires to see and how large he wishes to map it. This becomes important when an enlargment of a promising area is desired as was done in the D-3 to D-7 series. The use of other electives, of course, allows greater flexibility in terms of the variety of different output displays that one may achieve; the symbolism and value range intervals are the main electives used.

For most of the maps in Phases I and II only changes in the data banks and subroutine instructions and in certain electives of the F-MAP package were required from map to map. In general, maps were run in a series of six or more maps at a time. The maps run and the changes from run to run are described below. A sample F-MAP package is shown in Figure 3.

---

*For the study area only the first 9 electives were used, with one exception: for the search radius maps, elective 35 was also used. For the detailed study area the matrices of values were output onto disk files using Elective 21.

For maps A-2 thru A-4 and A-6 thru A-8 the same electives in the F-MAP package were used, with only the titles being changed. These electives were numbers 1 thru 9 which were used as follows:

| Elective Number | Description |
|---|---|
| Elective 1 | Output size--specified to produce maps at a 26" width. |
| Elective 2 | Extreme points--specified in terms of map inches from an origin of 0,0. The vertical dimension of the source map is 77.7 inches and the horizontal dimension is 69.7 |
| Elective 3 | Number of levels--nine for the purposes of contouring. |
| Elective 4 | Value Range Minimum--specified at 0.5; values below this level shown in a unique symbolism. |
| Elective 5 | Value Range Maximum--Specified at 5.0; values above this maximum shown as a unique symbolism. |
| Elective 6 | Value Range Intervals--specifies the ranges of each of the class intervals. |
| Elective 7 | Symbolism--user-specified symbolism in 9 separate levels. |
| Elective 8 | Contour Lines--suppresses the appearance of white bands between the levels on the map. |
| Elective 9 | Histogram Bars--suppresses the appearance of a histogram below the map. |

```
F-MAP
        FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (LOW)
    EXPRESSED AS A PERCENT BY COUNTY
    1                      26.0
    2             0.0      0.0       77.7      69.7
    3              9.
    4             0.5
    5             5.0
    6             0.5      0.5       0.5       C.5       0.5       0.5
                  0.5      0.5       0.5
    7
.-=+*XXHN 123456789  LOH  /
 -=-*-=HZ             X
      =I-             A
       IN             V
    8
    9
99999
```

FIGURE 3
Sample F-MAP Package

For Phase II the same electives in the F-MAP package were used for maps B-2 thru B-4 and B-9 thru B-11. For maps B-5 thru B-7 and B-12 thru B-14 elective 3 was changed to 1 level to show the critical isoline of 0.5% and 1.0% sulfur content; elective 7 was changed accordingly and elective 5 was changed to 1.0.

For maps B-16 thru B-21 and C-2 thru C-7 the same electives as in Phase I were used, with the addition of elective 35 specifying the maximum search radius at either 5 miles (1.340 inches) or 10 miles (2.681 inches). In addition, the outline package was removed and converted to a C-OTOLEGENDS package for maps B-14 thru B-21. No outline had been prepared for the Middle Kittanning Bed.

For maps D-4 thru D-7 the same electives as in Phase I were used, with the exception of elective 2--extreme points of (17.6, 27.0) and (48.4, 53.0) for D-4 and D-6 and (17.6, 40.0) and (33.0, 53.0) for D-5 and D-7. For map D-3 elective 1 was 13" and elective 2 had extreme points of (35.9, 47.9) and (45.9, 57.6); otherwise the electives were similar to maps B-2 thru B-4 for the left-hand map and B-5 thru B-7 for the right-hand map. The boxes in maps D-4 and D-6 showing the portion of the study area to be blown up were put in with a C-OTOLEGENDS package. The same legend was used in the blow-ups (maps D-5 and D-7) but the legend was overriden by the map border.

The base maps--Figures A-1, A-5, B-1, B-8, B-15, and C-1--were produced in the same manner as maps A-2, A-6, B-2, B-16, and C-2 with the following exceptions. First of all, different symbolism was employed so that the area outside the study area would be shaded and the data point locations would stand out as black squares. Second, the number of analyses was shown as a C-OTOLEGEND above each data point. These legends were created by a special data handling program.

The electives for the detailed study area were as follows:

| Elective | Description |
|---|---|
| 1 | 13" |
| 2 | extreme points from source map |
| 3 | nine levels |
| 4, 5, 6, 7 | same way as Phase I & II |
| 8 | same way as Phase I & II |

Maps E-2 thru E-4, E-6 thru E-8, E-9 thru E-11, F-1 and F-2, G-2 thru G-5, and G-8 thru G-10 were all run with SYMAP with changes occurring only in electives 4 and 5, and in elective 1 from Stage One to Stage Two. Maps E-1, E-5, and G-1 were base maps; these were run with special symbolism and used only a 'dummy' subroutine. The other maps of the detailed study area were run with GRID and SYMVU.

## 3.5. DATA HANDLING CONSIDERATIONS

When series of maps are to be run there are a number of considerations that can prove useful and time saving. These include:

(1) procedures for the multiple submission of maps, and,

(2) data bank storage and access requirements.

The multiple submission of maps can be accomplished quite easily with the SYMAP program. If maps are being made for the same study area and set of data points, then only the E-VALUES and F-MAP packages have to be varied from map to map with SYMAP.* Four maps with SYMAP might have the following order for the packages:

| | | |
|---|---|---|
| 1. | A-OUTLINE | |
| 2. | B-DATA POINTS | |
| 3. | C-OTOLEGENDS | |
| 4. | E-VALUES | 1 |
| 5. | F-MAP | 1 |
| 6. | E-VALUES | 2 |
| 7. | F-MAP | 2 |
| 8. | E-VALUES | 3 |
| 9. | F-MAP | 3 |
| 10. | E-VALUES | 4 |
| 11. | F-MAP | 4 |

If the data for the E-VALUES packages were on tape or disk and the electives did not change from one F-MAP package to the next, then very few cards would actually be required after the first F-MAP package--a minimum of 3 per E-VALUES package and 6 for F-MAP.

For example, *all* of the mapping for Phases I and II could have been done by using one basic set of A-OUTLINE, C-OTOLEGEND, and C-LEGEND packages for all runs and interchanging the appropriate B-DATA POINTS, E-VALUES and F-MAP packages. However, experience has shown us that it is worth the extra effort at the beginning of a study to duplicate outline and legend packages and set up separate decks for each series of maps to be run. Otherwise, considerable confusion can occur from constantly switching and alternating the various packages.

---

* see section 1 of the *Computer Program Manuals*.

When maps for a study area are to be run continuously over a long period of time, it would be advisable to store the outline and legends on a tape or disk file, store the data banks of data points and values on other files, and submit card decks for each run which contain only the map package, user subroutine, and job control language.

In Phase I one of the series of maps run was the sulfur content for washed samples for the Pittsburgh Bed. In this case all data were on cards. The deck set-up to produce the three maps for low, mode, and high values was as follows:

1. job control language.
2. user-subroutine FLEXIN, used to read in the appropriate values for mapping.
3. outline package.
4. data points package, containing the x-y locations for the washed samples.
5. legends packages.
6. data bank or values packages, containing the data for the low, mode, or high values for each county, alternating with:
7. map execution packages.

Data bank storage and access requirements are very important to a study involving several series of maps. Most of the previous work dealing with SYMAP had used tapes as a means of storing output maps. This procedure works quite well when the number of tapes the user is handling is small, but as the number of output tapes increases so does the confusion and difficulty.

We often must take output from one map and use it as input to another and therefore needed to develop a technique to store the output of each computer run and to retrieve and use this output as input to further computer runs.

For example, the first run might map the mode values for sulfur content and the second run the thickness of the bed. A third run is then desired to calculate the quantity of coal with less than 1% sulfur content, using the first and second runs. It is necessary to have an efficient technique for storing the matrices of values created by the first two runs and then retrieving them to produce the map in the third run.

A disk storage device was used to store all of the output maps that were run for the detailed study area of Phase III. The procedures involved are almost identical to those used with tapes. Minor modifications were made in the SYMAP program to add the necessary job control language cards and to specify the needed parameters for writing on disks. The following steps were necessary to set up this procedure:

1. Acquiring a 2314 disk pack from the Harvard Computing Center to be used for storing the basic information. The SYMAP source program was also stored on this disk for reasons of efficiency.

2. Developing the job control language (JCL) needed for each run, which is a fairly straightforward procedure. As SYMAP is currently set up to write its output on channel 8 for tape, this channel was used to write output onto disk.

## 4. GRID AND SYMVU TECHNIQUES

The requirements for preparing data for the GRID and SYMVU programs are much simpler than with SYMAP. This is particularly true for the types of applications useful for the computer mapping of coal reserves by sulfur level.

The general requirements of each program were discussed in Section 2: Computer Mapping Programs. The Computer Program Manuals (part 2 of this report) cover the procedures for coding all information in detail. This section is designed as an introduction to the manual procedures and as a description of how the program was used for the study area.

## 4.1. GRID VERSUS SYMAP

Whereas SYMAP accepts information at irregularly spaced data points, such as mine locations, and then interpolates values at all points on an assumed surface, the GRID program requires that a value be read in for every grid cell. These values are then displayed directly without interpolation. The GRID program was used for the detailed study area to determine and map quantity of coal at each grid cell (where the sulfur content was less than 1%), based on the values for bed thickness previously mapped with the SYMAP program. GRID was also used to produce composite maps of quantity of coal for more than one bed; here the quantity for each of the beds was summed at every grid cell location.

To produce a map, the user normally provides three sets of instructions and has the option of providing a fourth set. The instructions are prepared in the following packages: Data Package (usually a separate tape or disk file), Map Package, Irregular Outlines Package (Optional), and Subroutine Flexin.

For applications of the program such as those undertaken for the study area, it is necessary to specify only the user subroutine and the MAP package, once the SYMAPs are generated and the values saved.

With the SYMAP program it is necessary to specify information for the outline, data points, legends, values, and map electives in separate packages. The corresponding instructions for the GRID program are as follows if the program is used in the same way as for the detailed study area:

1. Outline--the GRID program reads in a rectangular matrix of values created by SYMAP; Subroutine FLEXIN of GRID is used to check each cell to see it it is outside the study area. The user does not need to code any separate outline package.

2. Data points--each cell on the rectangular grid that is inside the study area is a data point. These cells are read in according to a format specified in Subroutine FLEXIN; there is no separate data points package.

3. Legends--the same legends that appear on the maps produced with SYMAP can be used for maps produced with GRID. One subroutine is changed in SYMAP so that the legends can be output onto disk; likewise, a subroutine is changed in GRID so that these legends can be read in automatically.*

4. Values--the values are read in cell by cell according to the instructions in Subroutine FLEXIN. In the typical case--calculating quantity of coal--the sulfur content was read in cell by cell; if a cell was

---

*The necessary program changes are discussed in the Computer Programs Manual, Section 8.

inside the study area and the value for sulfur content was less than 1%, then the bed thickness for that cell was read in. An algorithm was used to calculate quantity in tons per acre, based on the bed thickness; the value for this cell was then returned by the Subroutine to the main program for mapping. If the cell was outside the study area (total outcrop, or greater than 28" thick outlines) or the sulfur content was found to be equal to or greater than 1%, then no value was returned and this cell was coded with the symbolism for background; a new outline for the area to be mapped was therefore created by the test for sulfur content. No separate values package was needed for the detailed study area, nor should it be required for most applications of the technique.

5. Map package--title cards and electives are coded in the same way as with the SYMAP program; many of the electives are exactly the same.

## 4.2. SUBROUTINE FLEXIN WITH GRID

Subroutine FLEXIN is the Fortran subroutine which allows the user to specify the format of the data. It is identical in use to the user subroutine of SYMAP; however, with the GRID program the subroutine must always be used to specify the format for reading in the values.

When maps were run with SYMAP the matrices of map values were written out on a disk to create two data banks--one containing all the SYMAPs for Stage One and the other containing all the SYMAPs for Stage Two. The values for each data bank were stored as real numbers and the entire data bank read in by Subroutine FLEXIN of GRID. Figure 4 shows the subroutine used for the Stage One mapping of the detailed study area.*

In most cases FLEXIN was used in GRID to read in values for sulfur content and thickness; if the cell were inside the study area and the sulfur content was less than 1%, then a value for quantity--porportional to the bed thickness--would be returned to the main program for mapping. Maps F-3 thru F-5 and H-1 thru H-5 were produced using this type of FLEXIN.

Since the scale of the map is known and the area in acres of each grid cell can be determined, only a few statements would need to be added to the subroutine to calculate the total quantity of coal. This would involve summing the quantity in tons per acre for all cells being mapped and multiplying the sum times the acres per grid cell.

Subroutine FLEXIN was used in GRID in a second way. For Maps G-6, G-7, and H-7 values were read in, the check for background cells was made (cells outside the study area), and the difference in values calculated. This is similar to the use of Subroutine MANIP for the four-state area.

## 4.3. MAP PACKAGE WITH GRID

The MAP package permits the user to specify the precise form of the map output in terms of various electives.

---

* The notes to the table explain some of the statements used. The discussion of Subroutine FLEXIN under the GRID program in the Computer Program Manuals should be consulted for a more detailed explanation.

```
      SUBROUTINE FLEXIN(IFCRM,T,FIRST)
      LOGICAL FIRST
      DIMENSION Z(16),IZ(16)
      EQUIVALENCE(Z(1),IZ(1))
      READ (12) Z
      GO TO (1,2,3,4,5,6),IFCRM
    1 CONTINUE
      IF(Z(2).GE.1.0) GO TO 10
      IF(IZ(7).EQ.25) GO TO 10
      T=1676.0*(Z(7)/12.0)
      RETURN
    2 CONTINUE
      IF(Z(5).GE.1.0) GO TO 10
      IF(IZ(8).EQ.25) GO TO 10
      T=1676.0*(Z(8)/12.0)
      RETURN
    3 CONTINUE
      IF(Z(10).GE.1.0) GO TO 10
      IF(IZ(15).EQ.25) GO TO 10
      T=1676.0*(Z(15)/12.0)
      RETURN
    4 CONTINUE
      IF(Z(13).GE.1.0) GO TC 10
      IF(IZ(16).EQ.25) GO TO 10
      T=1676.0*(Z(16)/12.0)
      RETURN
    5 CONTINUE
      IF(Z(2).GE.1.0.AND.Z(10).GE.1.0) GO TO 10
      IF(IZ(7).EQ.25.AND.IZ(15).EQ.25) GO TO 10
      A=1676.0*(Z(7)/12.0)
      B=1676.0*(Z(15)/12.0)
      T=A+B
      RETURN
    6 CONTINUE
      IF(Z(5).GE.1.0.AND.Z(13).GE.1.0) GO TO 10
      IF(IZ(8).EQ.25.AND.IZ(16).EQ.25) GO TO 10
      A=1676.0*(Z(8)/12.0)
      B=1676.0*(Z(16)/12.0)
      T=A+B
      RETURN
   10 T=-999999.0
      RETURN
      END
```

FIGURE 4
Subroutine FLEXIN with Grid

## Notes on Subroutine FLEXIN with GRID:

Line number:

1 The arguments transferred to the subroutine are: IFORM, used to specify (in Elective 2 of the MAP package) the number of the manipulation, or map, being made; T, the variable name by which values are returned to the main program; and FIRST, a logical variable which can be used to rewind the data file on the first call to the subroutine.

3. Dimensioning of sixteen sulfur content and thickness variables as real and integer numbers; Z(7), Z(8), Z(15), and Z(16) are the thickness variables for Upper Freeport total outcrop, Upper Freeport area over 28", Upper Bakerstown total outcrop, and Upper Bakerstown area over 28", respectively.

5. The sixteen variables are read in from the data file, one call at a time.

7. thru 11. For IFORM=1 (the first map and first manipulation), the statements between "continue" and "return" control the mapping of the quantity of coal, based on the mode values of sulfur for the Upper Freeport Bed for the total outcrop area. (Figure F-3, left). The other statements perform manipulations as follows:

| Statement No. | IFORM | Map | Figure |
|---|---|---|---|
| 12 thru 16 | 2 | Upper Freeport, 28" | F-3, right |
| 17 thru 21 | 3 | Upper Bakerstown Total | F-4, left |
| 22 thru 26 | 4 | Upper Bakerstown, 28" | F-4, right |
| 27 thru 33 | 5 | Composite, total | F-5, left |
| 34 thru 40 | 6 | Composite, 28" | F-5, right |

FIGURE 4 Contd

| line number | |
|---|---|
| 8 | checks to see if sulfur content greater than or equal to 1%; if it is, goes to statement no. 41. |
| 9 | checks to see if cell is outside outline; if it is, goes to statement no. 41. |
| 10 | Calculates quantity, based on thickness for the cell. |
| 11 | Returns value for quantity to be mapped. |
| 41 thru 42 | Sets value equal to background number for cells outside area to be mapped and returns this value to the main program. |

FIGURE 4 Contd

It is similar to the MAP package in SYMAP; many of the electives are specified with exactly the same format. Most of the maps for the detailed study area employed the same electives for SYMAP and for GRID:

| Elective | SYMAP | GRID |
|---|---|---|
| 1. | 13" | 100 rows by 120 columns for Stage One;<br>76 rows by 129 columns for Stage Two. |
| 2. | extreme points from source map | IFORM number related to the execution statements in FLEXIN |
| 3. | nine levels | nine levels |
| 4, 5, 6, 7 | same way as Phase I and II | same way as Phase I and II |
| 8. | same way as Phase I and II | (not used.) |

Maps E-2 thru E-4, E-6 thru E-8, E-9 thru E-11, F-1 and F-2, G-2 thru G-5, and G-8 thru G-10 were all run with SYMAP with changes occurring only in electives 4 and 5, and in elective 1 from Stage One to Stage Two.

Maps F-3 thru F-5 in Stage One and maps G-6, G-7 and H-1 thru H-7 in Stage Two were run with GRID. Changes occured in electives 2, 4, and 5, and in elective 1 from Stage One to Stage Two.

Maps E-1, E-5, and G-1 were base maps; these were run with special symbolism and used only a 'dummy' subroutine.

## 4.4. SYMVU INPUT REQUIREMENTS

The user of SYMVU needs to supply a matrix of surface values and a set of parameters specifying the type of oblique view desired. The matrix of values is provided directly on a data file by the SYMAP or GRID program with one value for each cell or printer character location mapped.

For the detailed study area two three-dimensional views were produced for each of four surfaces using the SYMVU program. These surfaces had been produced by SYMAP and the matrices of values stored on disk files for later use by the GRID program; they are stored and read in by SYMVU in a similar way. No changes were necessary in the present version of the SYMVU program to produce these eight plots.

The user of SYMVU must specify a number of electives, similar in nature to the electives of the F-MAP or MAP packages of SYMAP and GRID. These are all contained on two control cards which follow the title card. Figure 5 shows these three cards for the two views of the surface of thickness for the Upper Freeport Bed, for areas over 28" thick (the right-hand map in Figure F-1).

For example, the '100' and '129' at the beginning of card 2 specify the number of rows and columns, respectively, on the matrix of values and, correspondingly, on the SYMAP-produced map. It we examine Figure F-1 we will find that the numbers on the borders show that there are, indeed, 100 rows and 129 columns. These numbers were specified according to the instructions for electives 2-1 and 2-2, respectively; the other numbers on cards 2 and 3 were specified according to similar instructions in section 6 of the Computer Program Manuals.

```
U. FREEPORT BED,THICKNESS OF AREAS >28",GARRETT&ALLEGANY COUNTY,MARYLAND
 100 129       2       0       0               8    1       0  31    4
  60.   0.   6.        3.                                 .04
        92       110        14
        93       109        14
        93       110        14
        93       111        14
        94       108        14
        94       109        14
        94       110        14
        94       111        14
        94       112        14
        95       107        14
        95       108        14
        95       109        14
        95       110        14
        95       111        14
        95       112        14
        95       113        14
        96       106        14
        96       107        14
        96       108        14
        96       109        14
        96       110        14
        96       111        14
        96       112        14
        96       113        14
        96       114        14
        97       109        14
        97       110        14
        97       111        14
        98       109        14
        98       110        14
        98       111        14
U. FREEPORT BED,THICKNESS OF AREAS >28",GARRETT&ALLEGANY COUNTY,MARYLAND
 100 129       4       1       2               8    1       3  31    4   1
  45. 309.    6.       2.      28.0                       .04
```

FIGURE 5
Control Cards for SYMVU

The next 31 cards are used to specify the north arrow which is composed of 31 small five-pointed stars. At the present time all legends to be shown on the plot must be punched up separately with a card for each character cell. In Figure 4 the first and second integer (92 and 110, respectively) on card 4 are the row and column locations as they would be measured on the SYMAP-produced map; in this case a new legend was created for SYMVU; these points were not measured from the map in Figure F-1. The integer number, 14, is a code for the five-pointed star symbol. It is recommended that legends not be used with SYMVU until one is very familiar with the programs and mapping techniques.

The last three cards are the title card and two control cards for the second of two views of this surface. The card decks for the views of the other three surfaces were exactly the same, except for the title cards and the elective specifying the file number of the data set.

The choice of electives requires a great deal of trial and error, taking into account the particular surface and variable being displayed. Examples in Section 6 of the Computer Program Manuals demonstrate the use of many of the most helpful electives.

## 5. DISCUSSION OF STUDY AREA GRAPHICS

This section is designed to give examples, from the study area efforts, of the types of mapping possible and the problems that may be encountered. In many cases the maps are only exemplary and meaningful results should not be inferred, due to the lack of data available*.

### 5.1. FOUR-STATE STUDY AREA

Map series A contains all of the maps produced in Phase I for the Appalachian Coal Region. Figures A-1 and A-5 show the base maps for the Pittsburgh Bed, including the data point locations (washed and raw values, respectively) and the number of analyses assigned to each county. The low, mode, and high values for sulfur content are shown in Figures A-2 thru A-4 for washed and A-6 thru A-8 for raw samples, respectively. All six surfaces show a definite trend from high sulfur coal in the southwest (as high as 5.0%) to low sulfur coal (less than 1%) in the northeast and in Allegany and Garrett Counties in Maryland.

Map series B contains the maps produced in Phase II for the Pittsburgh bed. Figures B-1 and B-8 show the base maps, including the data point locations (washed and raw, respectively) and the number of analyses assigned to each town. When the base maps are run at this scale, some of the data points and legends showing the number of analyses are lost under the state boundary legends or under other data points. Some of the data points are actually superimposed and are shown by a "/" rather than a black square. Figure B-8 contains a box showing the detailed study area for the Phase III mapping of Allegany and Garrett Counties.

---

*In Volume One: Study Area Report the graphics are discussed in more detail, particularly in terms of the accuracy of the maps.

Figures B-2 thru B-4 show the low, mode, and high values for washed samples for each town; they have the same slope from low sulfur in the northeast to high sulfur in the southwest as in the county maps, but the surfaces are not as smooth, due in part to the greater number of data points and the uneven spread of points. Figures B-5 thru B-7 are identical to B-2 thru B-4 except for the value range intervals selected; the 'critical isolines' of 0.5% and 1% sulfur content are shown.

Figures B-9 thru B-11 show the low, mode, and high values for the raw samples and Figures B-12 thru B-14 the same surfaces for the critical value range intervals. We would assume that fewer areas would be shown as low sulfur (less than 1%) than with the washed samples; however, the opposite is true (compare Figures B-6 and B-13) due to the larger number of data points for raw samples and, particularly, the much larger number in the low-sulfur northeastern part of the study area (compare Figures B-1 and B-8). It is very important to refer to the base maps when comparing surfaces with different data bases.

A set of maps was run in Phase II using a limiting search radius of five or ten miles around each data point as the study area outline. This serves several purposes:

1) it is not necessary to take the time to code the bed outcrop as an outline, and

2) equal accuracy is maintained for all areas mapped; no symbolism appears for areas without data points, such as the southwestern part of Pennsylvania.

Figure B-15 shows the base map for this set of maps; the data point locations are exactly the same as those shown in Figure B-8. The portions of the study area enlarged in map series D are shown by rectangular borders. Figures B-16 thru B-18 show the low, mode, and high values for the raw samples with a five mile search radius. Figures B-19 thru B-21 depict the identical information with a ten mile search radius. In both cases the same values are mapped as were shown in Figures B-9 thru B-11; in fact, the only differences are in the effective study area outlines.

For the Middle Kittanning Coal Bed (map series C) the data for the raw samples were also mapped using a five and ten mile search radius. Figures C-2 thru C-4 show the low, mode, and high values for the raw samples with a five mile search radius; Figures C-5 thru C-7 depict the same information with a ten mile search radius.

These sets of maps do not give us very much information about the extent of the coal seam, or the extent at various sulfur levels. However, they give us as much and as accurate information in the vicinity of the towns (or mines) as if we had known the outcrop area and mapped it. We can choose our search radius based on the reliability we attach to the data and the number and spacing of data point locations. Five miles may be conservative in that the information conveyed graphically is scanty; on the other hand, ten miles may be misleading as to the extent of the coal seam in some areas. Finally, it is important to keep in mind that we are dealing with samples aggregated by towns and that the data point locations only represent the nearest town and not the actual mine or sample location.

Map series D includes: (1) surfaces comparing values for the Pittsburgh Bed as mapped by towns and mapped by counties (Figures D-1 and D-2), and, (2) enlargements of different parts of the study area for the surface shown in Figures B-10, B-13, and B-17. (Figures D-3 thru D-7).

The values for the interpolated surfaces generated from town data points were subtracted from the interpolated surfaces generated from county data points.* These surfaces were subtracted at a regular grid interval of about 9/10", or 9 miles on the source map. Figures D-1 and D-2 show absolute differences in sulfur content. It would have been more informative, in retrospect, to have shown the relative differences by positive and negative ratios.

Figure D-3 shows a portion of the surface of mode values for raw samples mapped by towns (Figures B-10 and B-13) enlarged to the scale of the Phase III maps. The same areas of Allegany and Garrett counties as mapped in Phase III are shown. Figure D-3 can be compared with Figure E-1, one of the base maps for Phase III. In Figure D-3 the line legends for the state and county borders were blown up from the Phase I and II base map while in Figure E-1 these legends were taken directly from the Phase III source map; the accuracy lost by enlarging from the small scale to the large scale is not significant. When a map is blown up from a small scale to a larger scale, the data points used for all of the smaller scale maps should be shown. Then, the true area used for the interpolation of the larger scale map will be evident and the reliability of the map better understood, even if only a small portion is mapped.

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*These surfaces were subtracted using a new subroutine in SYMAP. Subroutine MANIP; this is described in the last section of the Computer Program Manuals.

Perhaps the most meaningful maps produced in Phases I and II are Figures D-4 thru D-7. These maps show detailed portions of the study area outlined on the base map, B-15. The "cut-out" region of maps D-4 and D-6 appear at the original base map scale of 1:250,000 and thereby show the amount of detail that went into the preparation of the bed outline. One map was created using the regular SYMAP interpolation with an unlimited search radius (D-4) while the other was restricted to a 5 mile search radius (D-6); at this scale the search radius option produces circular shapes, rather than the 'squares' depicted in map series B and C.

The upper-right quadrant of each of these maps was blown up to twice the original size (or, to a 1:125,000 scale) to produce maps D-5 and D-7; this is the only case where maps were produced at a larger scale than the source maps. In Figures D-6 and D-7 the search radius was used as a study area outline and the bed outline was shown as a line legend for reference. When the bed outline and data points can be accurately located, we can use the bed outline as a study area boundary but limit interpolation (and symbolism) with a five mile search radius to areas inside the bed outline.

## 5.2. DETAILED STUDY AREA

Map series E contains the maps produced in Phase III, Stage One, showing sulfur content for the Upper Freeport and Upper Bakerstown Beds. Maps were produced for both the total outcrop and for the areas over 28" in thickness, using precisely the same data point locations and values in each case.

Base maps are shown in Figure E-1 for the Upper Freeport Bed and Figure E-5 for the Upper Bakerstown Bed.

In Figure E-1 only some of the data point locations show as black squares on the base map. Of the remainder two are superimposed at one location (in the cluster in the upper center) and the others occur under the state and county boundary legends. The full set of data points and accompanying information can be shown by running an additional base map with (1) no legends, (2) distinctive symbolism for the superimposed data points, and (3) the number of analyses shown as legends above each point as in Phase I and II. For the Upper Freeport Bed the original base map contained several other outcrop areas, mainly in the northwestern part of Garrett County. These were eliminated because there were no data points associated with them.

The question arose as to the validity of interpolating across the area between the smaller western syncline and larger eastern syncline (see Figure E-1). It is possible with SYMAP to place a barrier to prohibit or inhibit the interpolation when appropriate.* Since this area does not have complex geology, we could assume that geologic conditions when the coal beds were laid down were the same for both synclines and that the history since then has been relatively the same. Without any information to the contrary we therefore assumed that there was a single formation which was eroded in the middle to create the gap between the synclines. We then treated them as one formation and interpolated between synclines without the use of a barrier.

Figures E-2 thru E-4 and E-6 thru E-8 show the low, mode, and high values for sulfur content mapped by mines for the Upper Freeport and Upper Bakerstown Beds, respectively.

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*See Shepard, Donald S., 1970, "SYMAP Interpolation Characteristics", Computer Mapping as an Aid in Air Pollution Studies, Volume Two, Report L, Laboratory for Computer Graphics and Spatial Analysis.

With the shortcomings of the data in mind we can examine these maps of sulfur content. The maps show, in general, that the higher sulfur content coals (by percent) are located near the center of the study area in the Upper Freeport Bed; however, in the Upper Bakerstown bed, the higher concentration tends to be in the southwest section of the study area and the sulfur content decreases towards the center and the northeast section of the bed.

As an example, we can examine Figure E-3, the map of mode values for the Upper Freeport Bed. As shown on the base map (Figure E-1) the eastern syncline has one data point in the very north and several in the middle portion. The interpolation between these displays a gradation from a low concentration of sulfur in the north to a moderate amount in the middle portion of the syncline. In general, one should be very cautious of the extrapolation beyond the data points at the extremes of the region, and of the interpolation between data points which are fairly far apart. A misleading extrapolation is shown in the bottom left hand corner of Figure E-6; a potentially misleading interpolation is evident in the center of the same illustration.

The final set of maps in series E were composites of the sulfur content values for both the Upper Freeport and Upper Bakerstown Beds. These maps combined the A-OUTLINE, B-DATA POINTS and E-VALUES packages for both the Upper Freeport outcrop and Upper Bakerstown outcrop. Maps were then made which assumed that both beds were part of the same formation. Similar maps were made for the areas over 28" thick, for the low, mode, and high values. (see Figures E-9 thru E-11).

If we confine our interpretation to the areas surrounding data points, then the composite map can give us a quick and useful overview of any and all low sulfur coal areas for the beds we are interested in. The limiting search radius in conjunction with the outline would be very useful here, particularly for the areas over 28" thick.

Map series F contains the maps produced in Phase III, Stage One, showing bed thickness and quantity of less than 1% sulfur coal in tons per acre for the Upper Freeport and Upper Bakerstown Beds. Figures F-1 and F-2 show the bed thickness in inches for the Upper Freeport and Upper Bakerstown Beds, respectively. These figures also serve as the base maps for the thickness data. No base map changes are made from Map series E other than in the location of data points.

Figures F-3 and F-4 show the quantity of coal in the ground (in tons per acre) for those parts of the Upper Freeport and Upper Bakerstown Beds with less than 1% sulfur coal--based on the mode values for the raw samples. These are the first of the maps produced with the GRID program; a separate value is mapped for each cell or computer print position, based on the original maps, and no interpolation takes place.

Figure F-5 shows the total quantity in tons per acre for the Upper Freeport and Upper Bakerstown Beds combined. It is not a summation of Figures F-3 and F-4; it is derived from the composite sulfur content map (Figure E-10) and the combined thickness (the summation of Figures F-1 and F-2). Such a map can help locate areas of significant low sulfur coal that would yield a greater total quantity of coal when all mineable seams are considered. Ideally, we would include another variable such as overburden, so that the economics of mining could be included.

Figures F-6 thru F-8 are three-dimensional views of surfaces produced with SYMVU for sulfur content and bed thickness for the Upper Freeport Bed. Figures 6a and 6b show two views of the total outcrop for the mode values of sulfur; Figures 7a and 7b show the same values for the area over 28" thick. Figures 8a and 8b show the bed thickness for the total outcrop and Figures 9a and 9b for the area over 28" thick. These views were produced to demonstrate this type of graphical portrayal. A set of views of a surface from several different angles and altitudes can give a great deal more information about the whole surface than the isolines of a SYMAP or GRID two-dimensional representation. With special versions of the program, legends and isolines between levels--such as the isoline of 1% sulfur content--can be shown on the surface.

Map series G and H involved the mapping of washability data for the Upper Freeport Bed for the center portion of Allegany and Garrett Counties (shown in Figure F-1). Map series G was concerned only with the sulfur content resulting from the washed samples. The sulfur content that coal could be washed to at various yields using several screen sizes was mapped for the Upper Freeport Bed. Figure G-1 shows the base map for this series.

The total sulfur content and the sulfur content resulting if all pyritic sulfur were to be removed were mapped for purposes of comparison. Figures G-2 and G-3 show the total sulfur and total less pyritic sulfur for the 3/8" mesh screen at 60% yield for the total outcrop and the areas over 28" thick. Figures G-4 and G-5 show the same type of information for the 1 1/2" mesh screen. Figures G-6 and G-7 show that the difference in sulfur content between washing with a 3/8" and 1 1/2" mesh screens is small, except in the far northeastern corner of the study area. In all cases the sulfur content is greater with the 1 1/2" mesh screen.

The final set of maps in series G (Figures G-8 thru G-10) show the same type of sulfur information as Figure G-3 for the area over 28" thick but with different yields. For the particular analyses mapped, yields of 50%, 60%, 70%, or 80% do not significantly affect the sulfur content.

The last map series shows the quantity of coal that would be available, using the washability mapped in series G and the bed thickness mapped in series F. All of the maps in this series were produced with the GRID program.*

## 5.3. GRAPHIC TECHNIQUES

With the exception of the value range intervals, the map symbolism is the only and, therefore, the most important graphic way to portray the meaning of the data. The value of a map may be easily lost or destroyed by a poor choice of symbolism. In SYMAP this choice of symbolism is usually made by the program, which has a prestored set of symbolism for up to 12 levels.

For the study area it was felt that this set of symbolism was inadequate because (1) there was not enough differentiation between some of the levels, and (2) the darkness of adjacent levels seemed to be reversed in some cases. Therefore, a unique set of symbolism was devised.

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*In addition to maps H-1 thru H-7, maps F-3 thru F-5, G-6, and G-7 were run with the GRID program. All other maps were produced by SYMAP (except for F-6 thru F-9 which are SYMVUs).

An equal interval value range was used for most of the maps produced. It had nine graphic levels as well as a low and a high value symbolism for data exceeding the specified minimum and maximum values. Therefore, the task became one of determining the appropriate level breakdown for each of the types of computer maps and applying the standard symbolism to this breakdown.

The range and distribution of values from the initial maps for Phases I and II were reviewed and the decision made to map the sulfur content to the nearest 1/2%, with a maximum of 5% and a minimum of 0.5%. Symbolism was also assigned to the few values that might exceed the maximum and likewise to those areas that were below the minimum. The same level breakdown was used for the sulfur content data in Phase III.

For Phase II 'critical level' breakdowns were also used to emphasize the isolines of 0.5% and 1% sulfur content. Special symbolism was used for base maps in all three phases and for the surface comparison in Phase II.

In Phase III maps were produced for bed thickness and quantity of coal in addition to sulfur content. The level breakdown for bed thickness was 4" per level. After reviewing the minimum, maximum, and distribution of thickness values it was apparent that areas greater than or less than 28" thick were of particular interest. Therefore, level adjustments were made that reflected this 28" value; the minimum value set was 16" and the maximum 52".

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*The symbolism used, as coded in the F-MAP package, is shown in Table III-12 of the Appendices (Section III) of Volume One: Study Area Report; Also, in section I, Table I-2 summarizes the use of symbolism for the different map series and Table I-3 shows the various symbolism used.

Preliminary review of the values for quantity of coal indicated that a value range of 500 tons per acre seemed appropriate to use as the level breakdown. The minimum was set at 5000 tons per acre and the maximum at 9500 tons per acre, with special symbolism assigned for values exceeding the maximum or minimum values.

The final use and graphical reproduction are among the most important considerations. All but two of the final maps produced in Phases I and II were 26" wide, and these two plus all of the maps in Phase III were 13" wide. The maps were photographically reduced for publication in this report. The 26" maps were reduced to 25% of their original size and printed one to a page; the 13" maps were reduced to 30% of their original size and printed two to a page. Previous studies had demonstrated that such size reductions gave visually good results.

However, photographic reduction of the maps has certain difficulties. In particular, the legends may become illegible and the textual and statistical material printed below the map may lose much of its usefulness. Moreover, the tone discernability of the symbolism is somewhat reduced in almost direct proportion to the amount the maps were photographically reduced.

Some of the problems can be overcome by photographing the legends and explanatory information at another scale. In fact, this was done with the titles shown at the bottom of each page; these were separately photographed and stripped into the negatives before printing.

The best solution is to experiment at the beginning of a project to determine the optimum combination of study area size, reduction scale, and legend and explanatory information detail to use in the final presentation or publication of the maps.

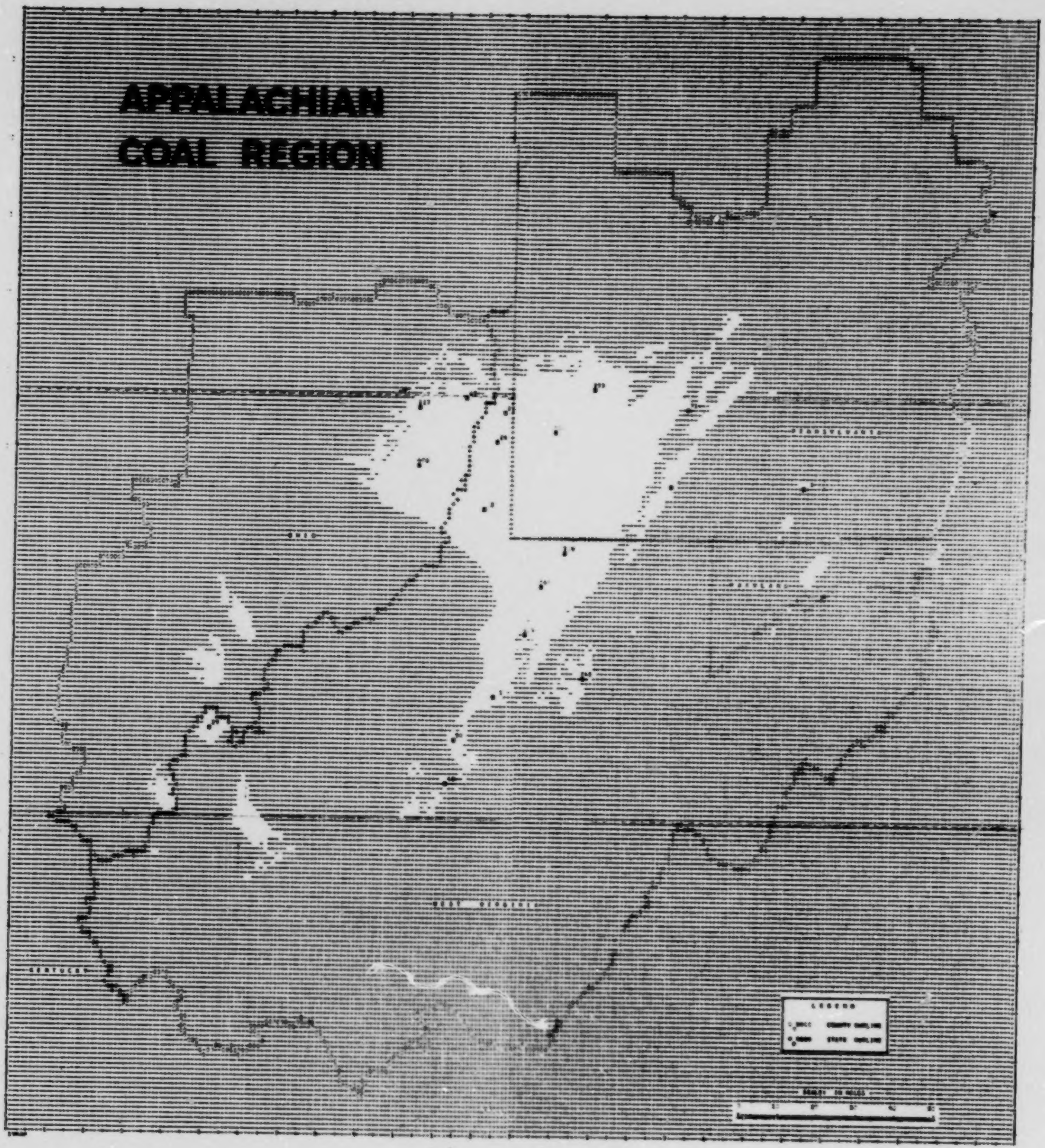

APPALACHIAN
COAL REGION

Figure A-1
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Number of Analyses for Washed Samples
Base Map

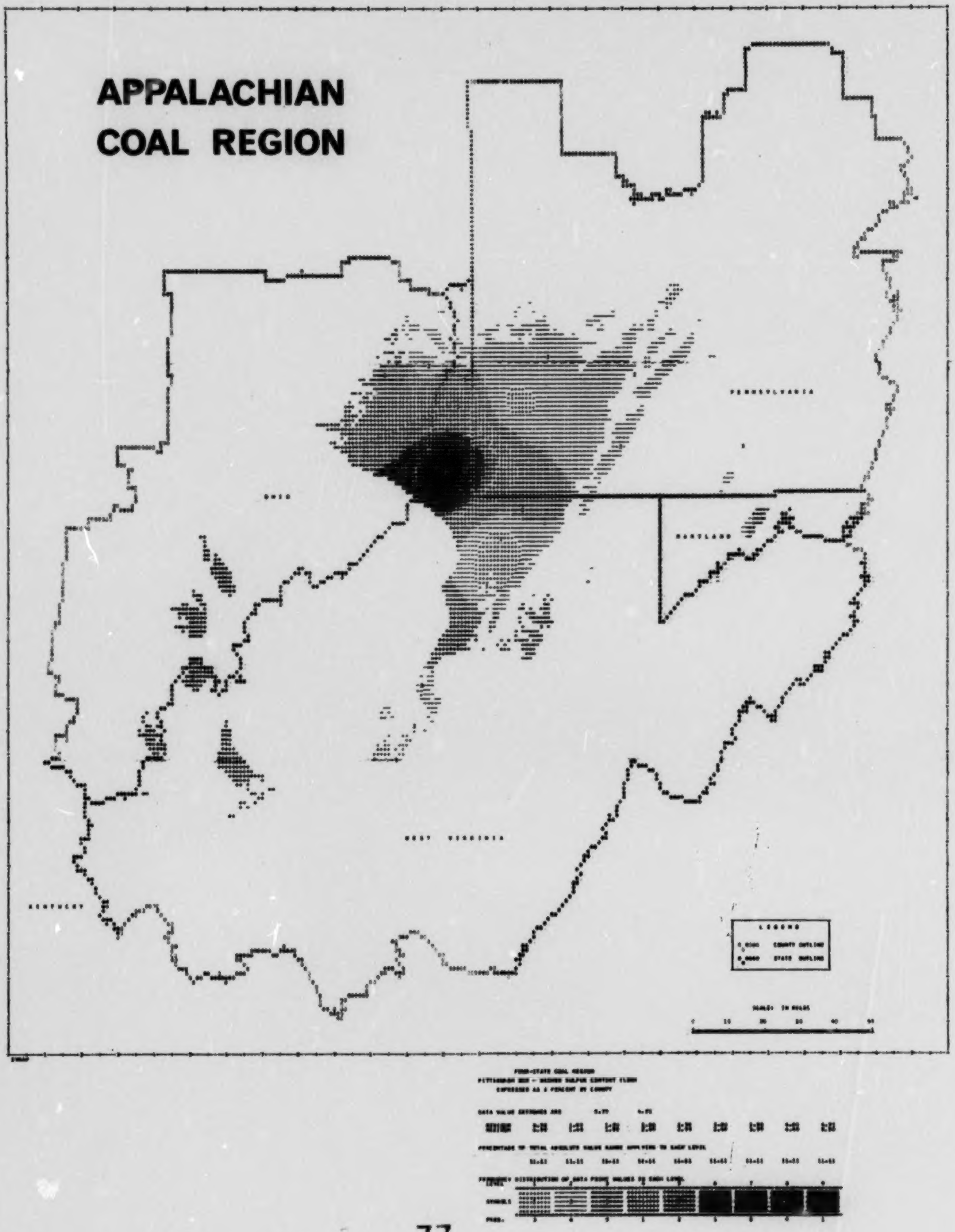

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0 10 20 30 40 50
FOUR-STATE COAL REGION
EXPRESSED AS A PERCENT BY COUNTY
DATA VALUE EXTREMES ARE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
1 2 3 4 5 6 7 8 9
SYMBOLS
FREQ.

Figure A-2
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Low Values for Washed Samples
(0.5% isoline interval)

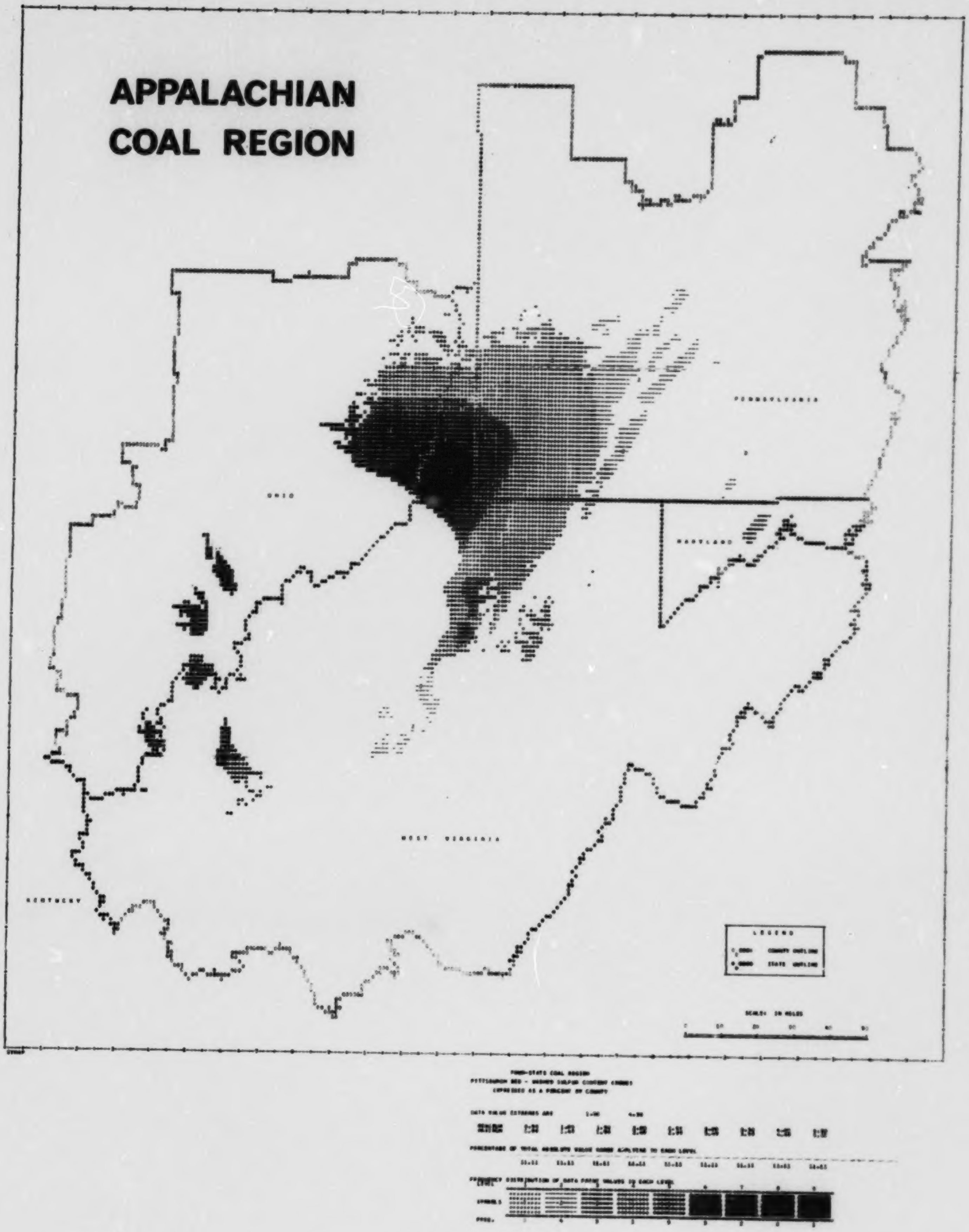

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SYMBOLS
FREQ.

Figure A-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Mode for Washed Samples
(0.5% isoline interval)

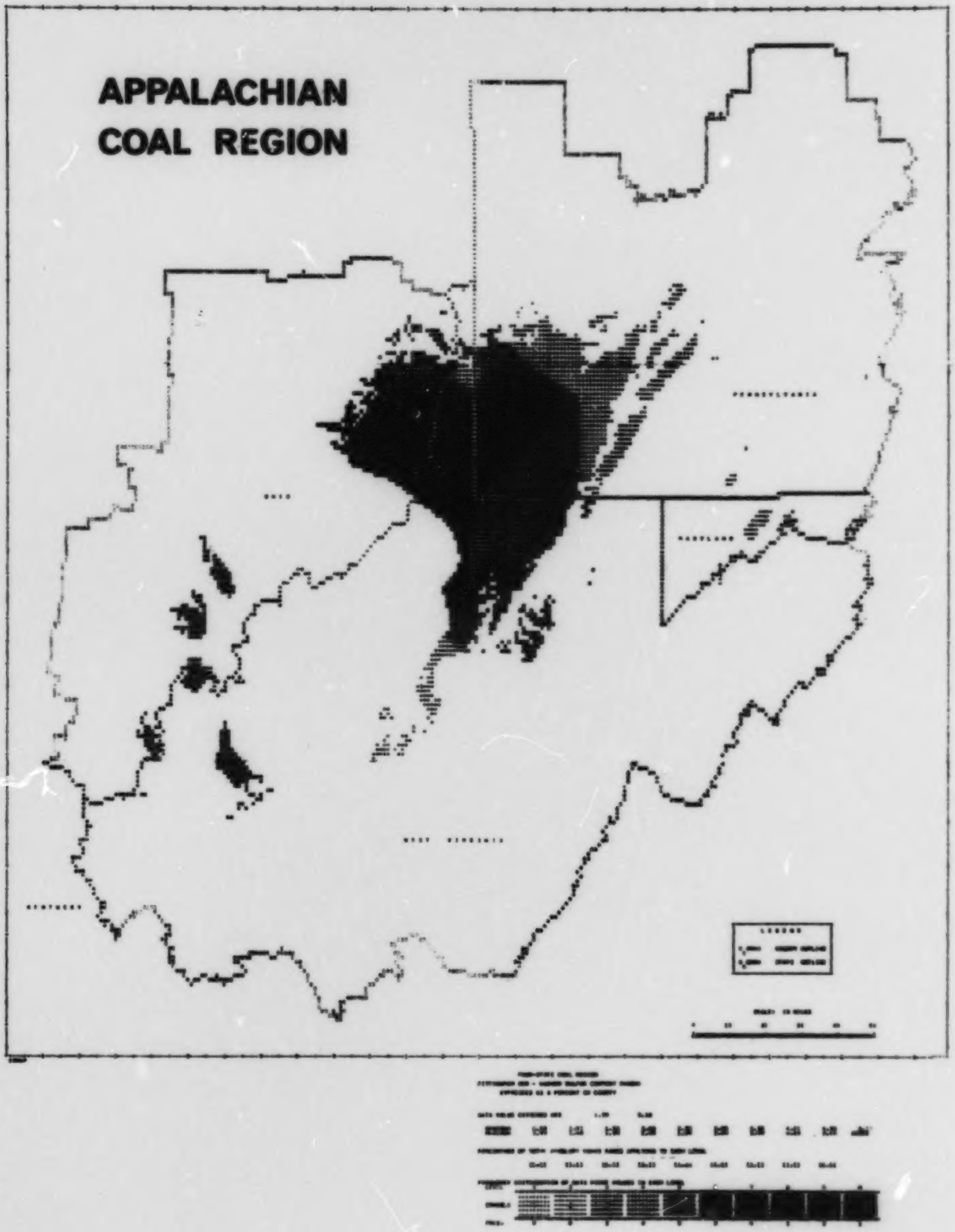

APPALACHIAN
COAL REGION

Figure A-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
High Values for Washed Samples
(0.5% isoline interval)

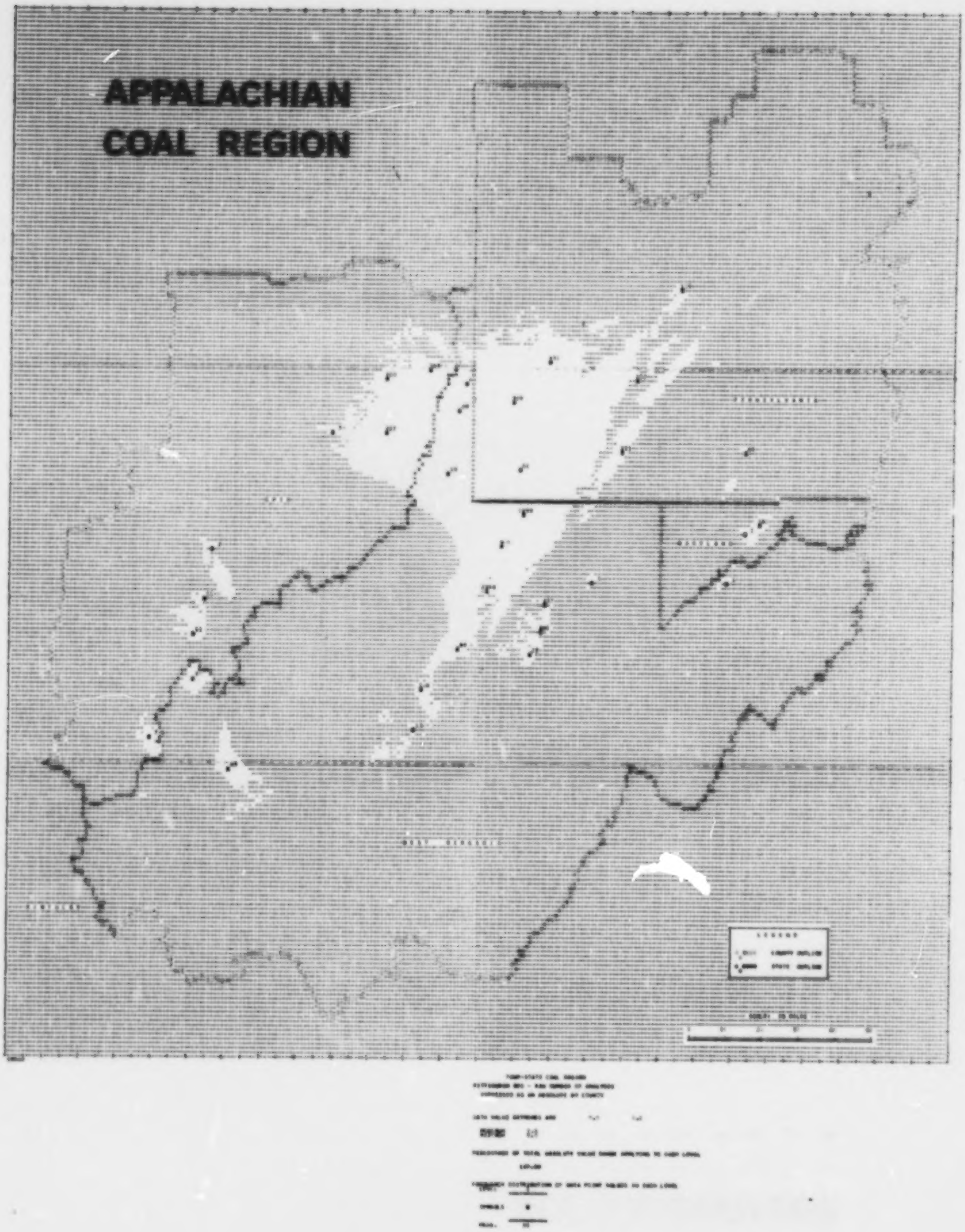
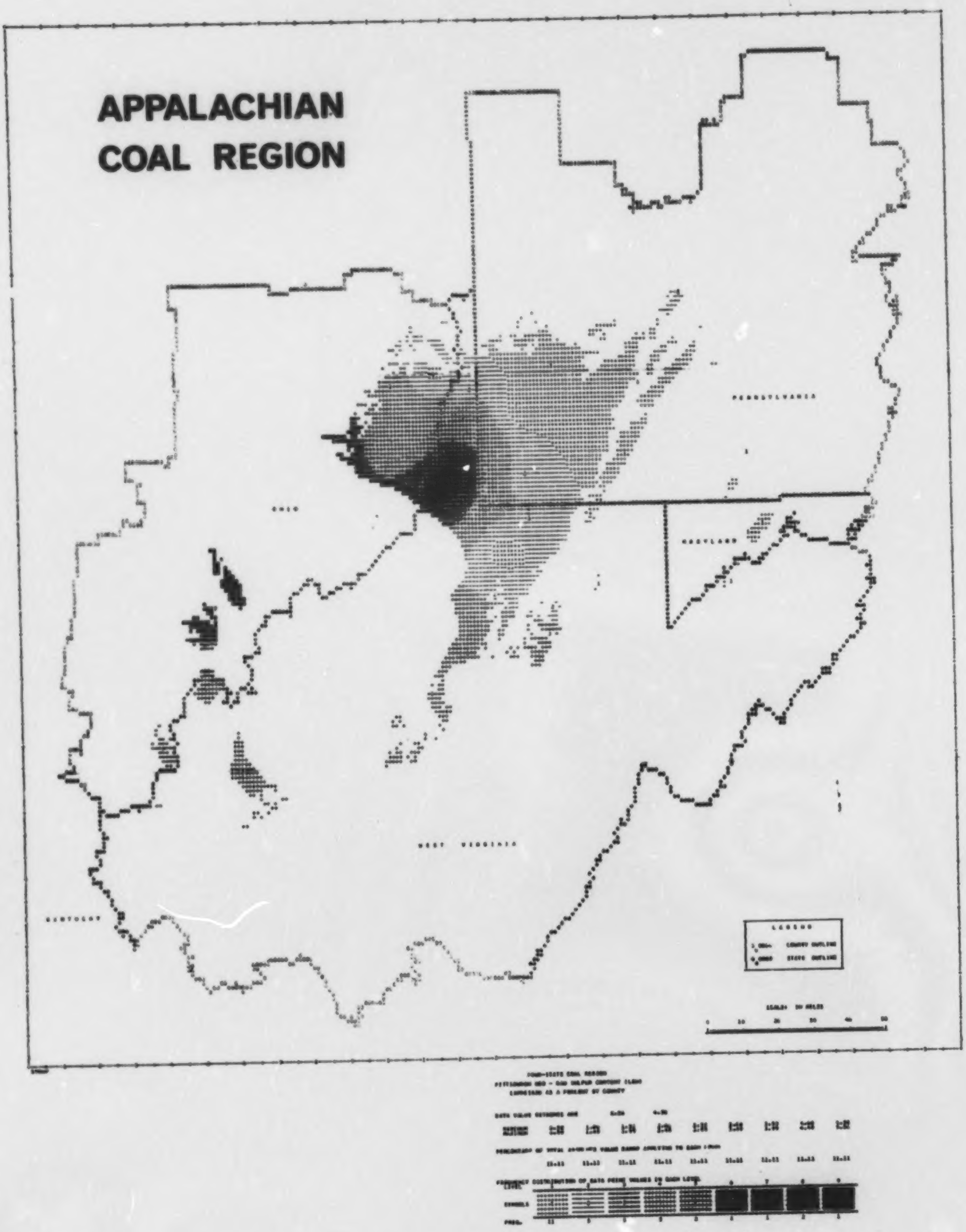

APPALACHIAN
COAL REGION

Figure A-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Number of Analyses for Raw Samples
Base Map



APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY

Figure A-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Low Values for Raw Samples
(0.5% isoline interval)

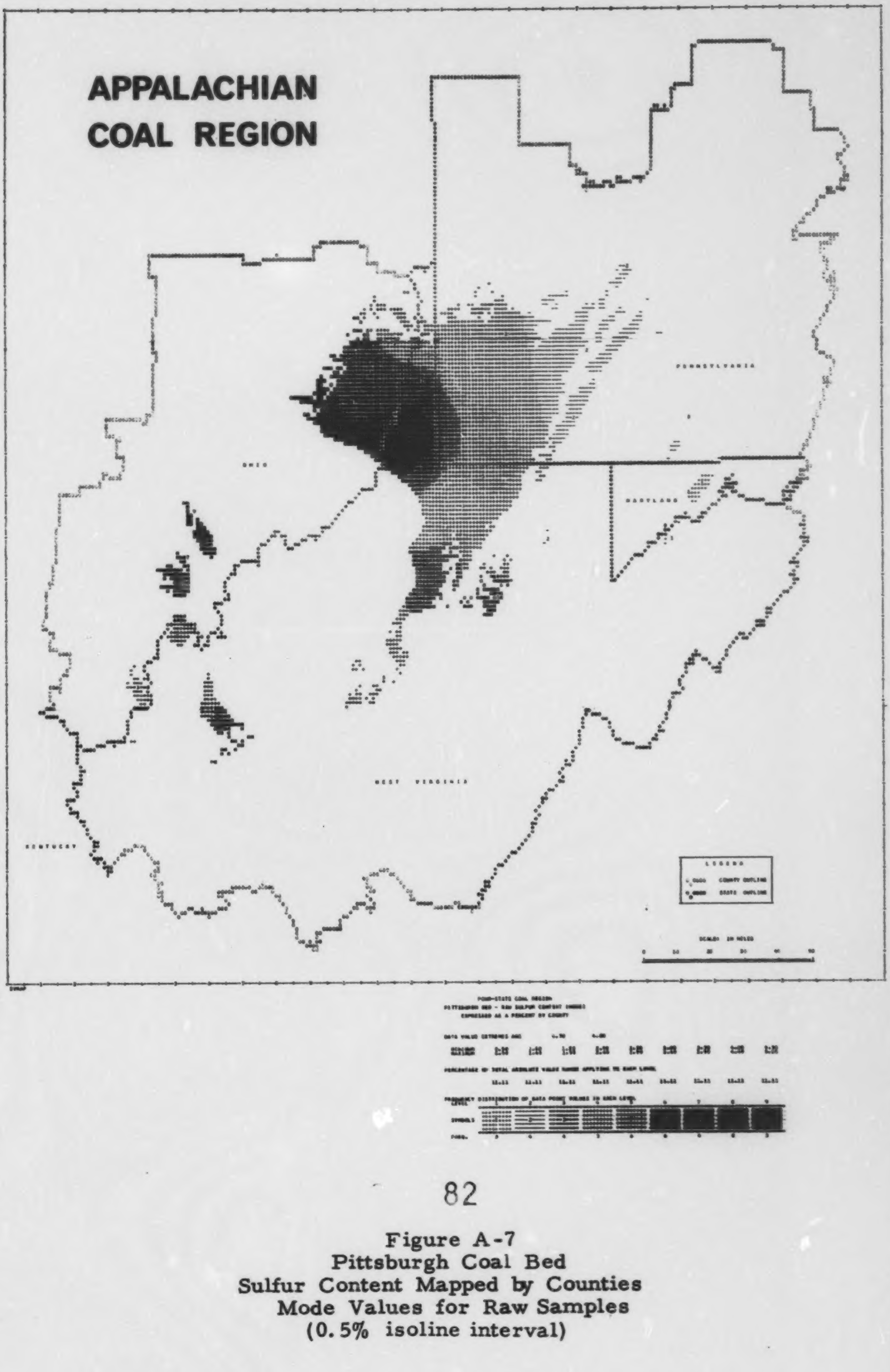

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE

Figure A-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Mode Values for Raw Samples
(0.5% isoline interval)

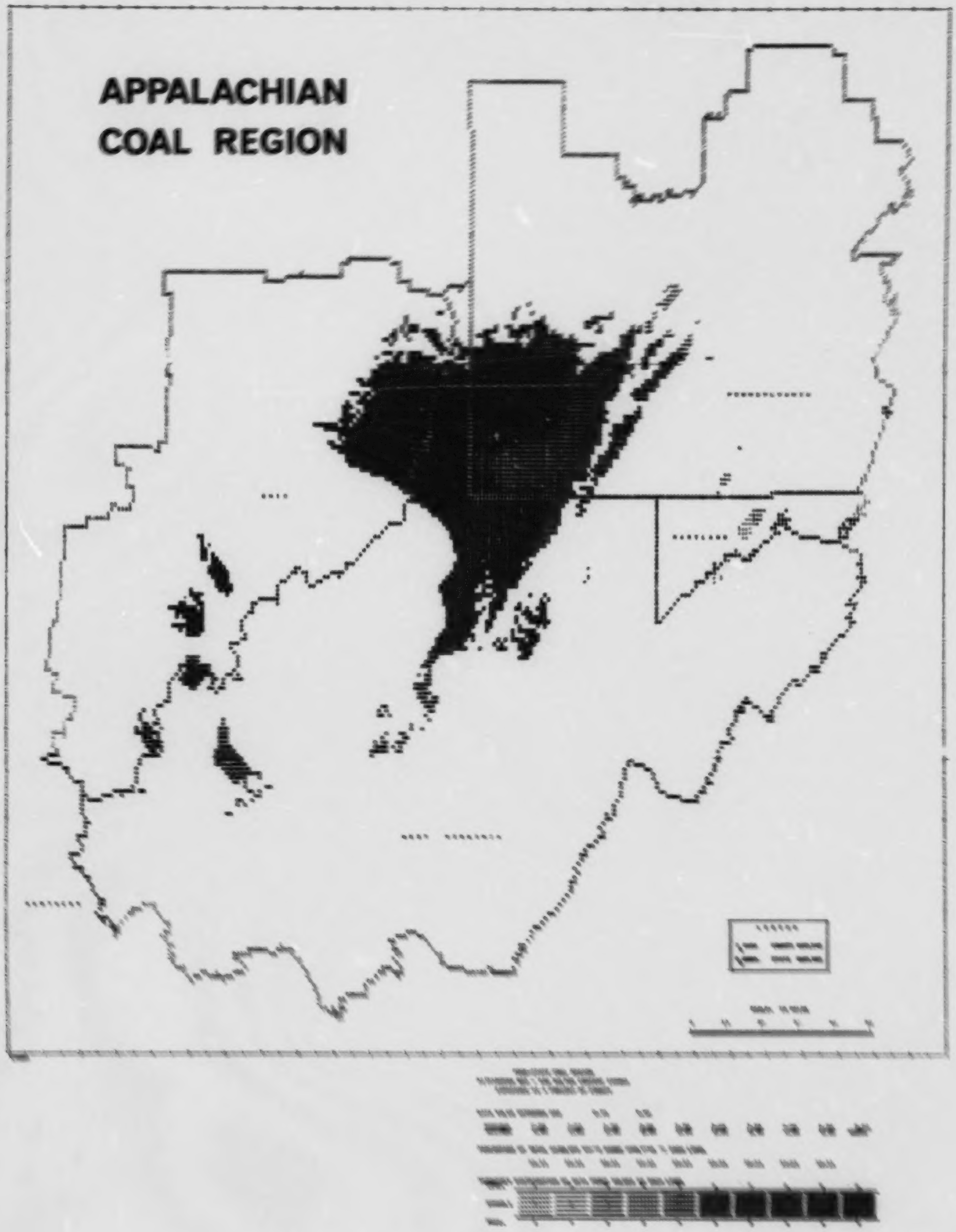

APPALACHIAN
COAL REGION

Figure A-8
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
High Values for Raw Samples
(0.5% isoline interval)

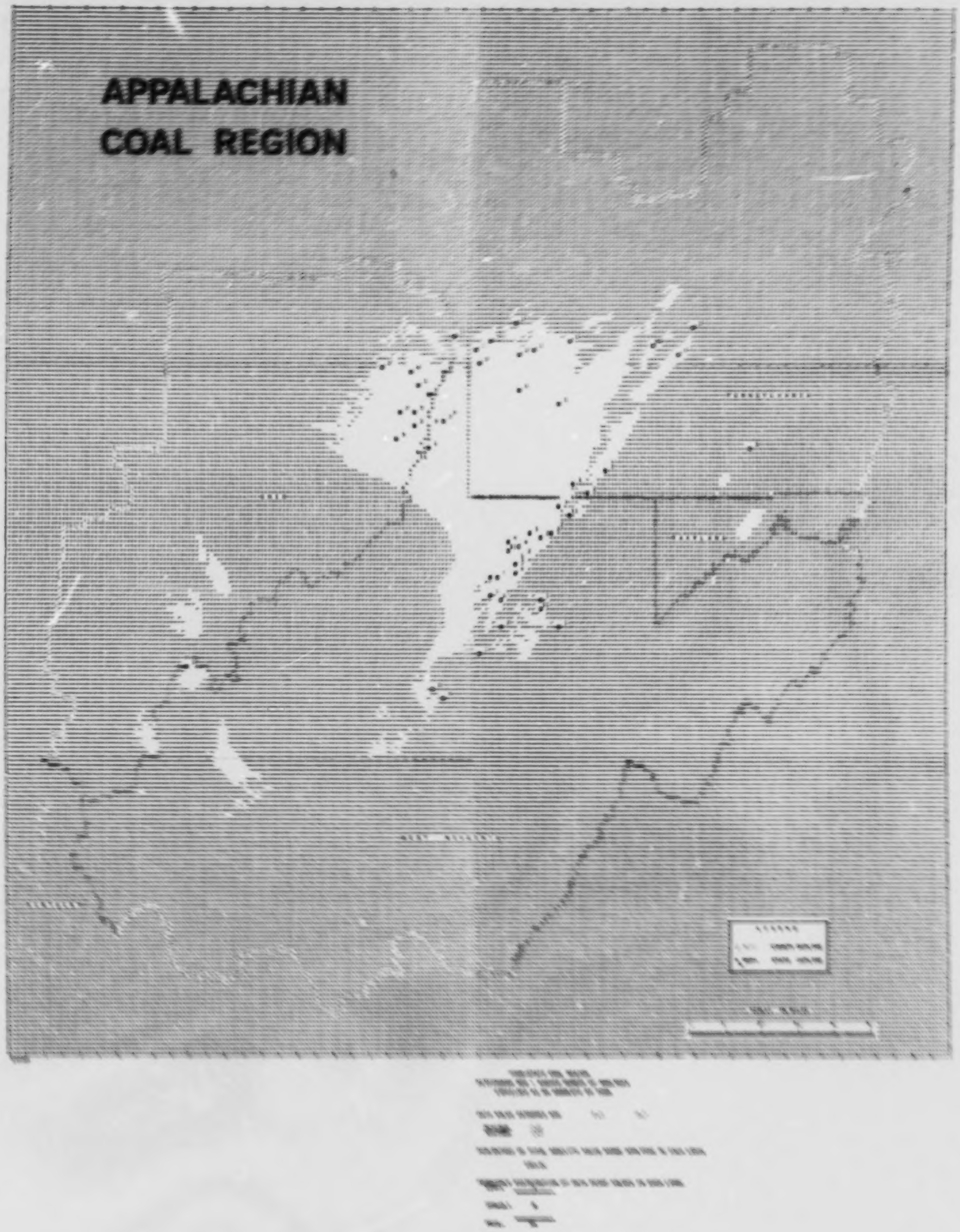

APPALACHIAN
COAL REGION

Figure B-1
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Washed Samples
Base Map

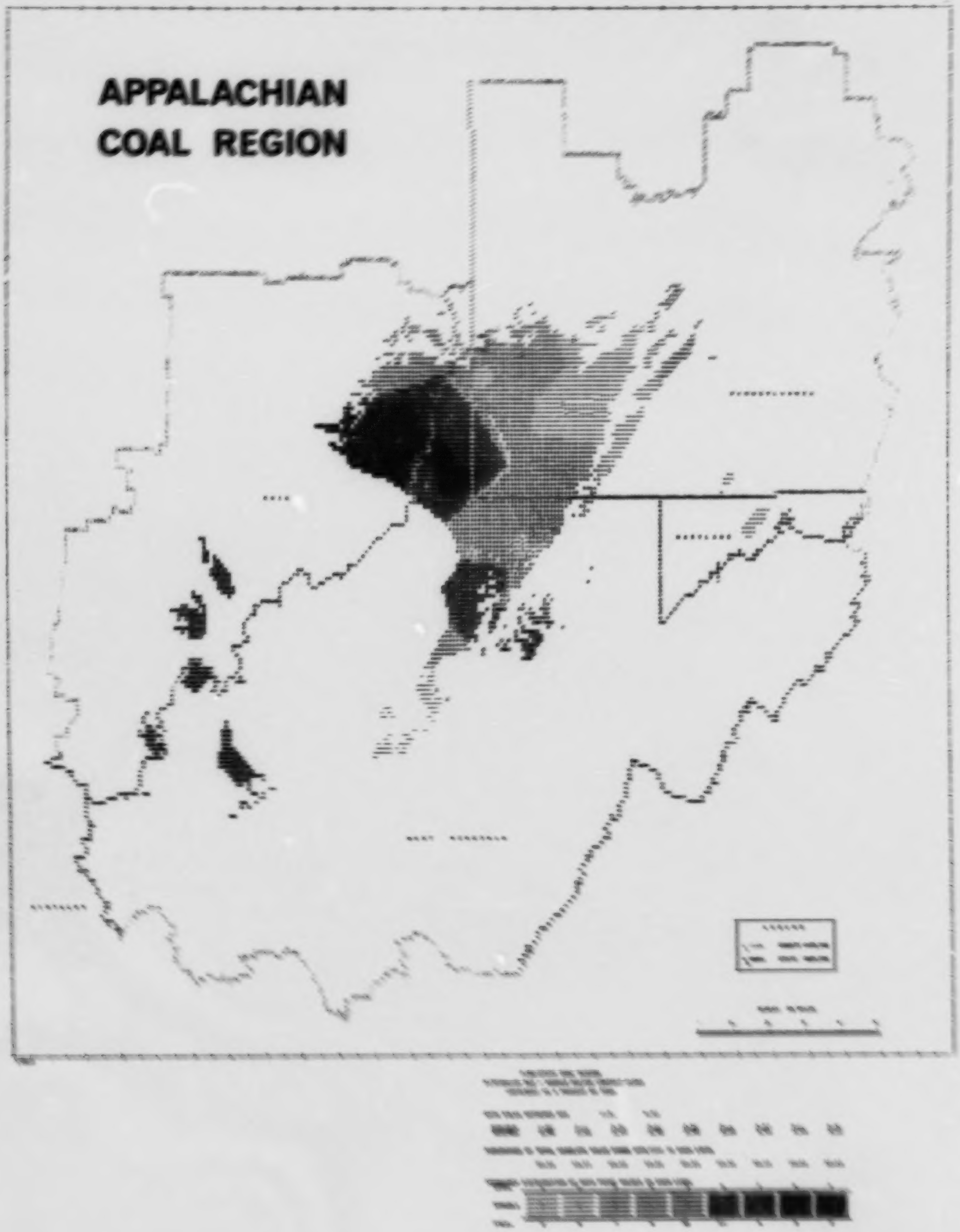

APPALACHIAN
COAL REGION

Figure B-2
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Washed Samples
(0.5% isoline interval)

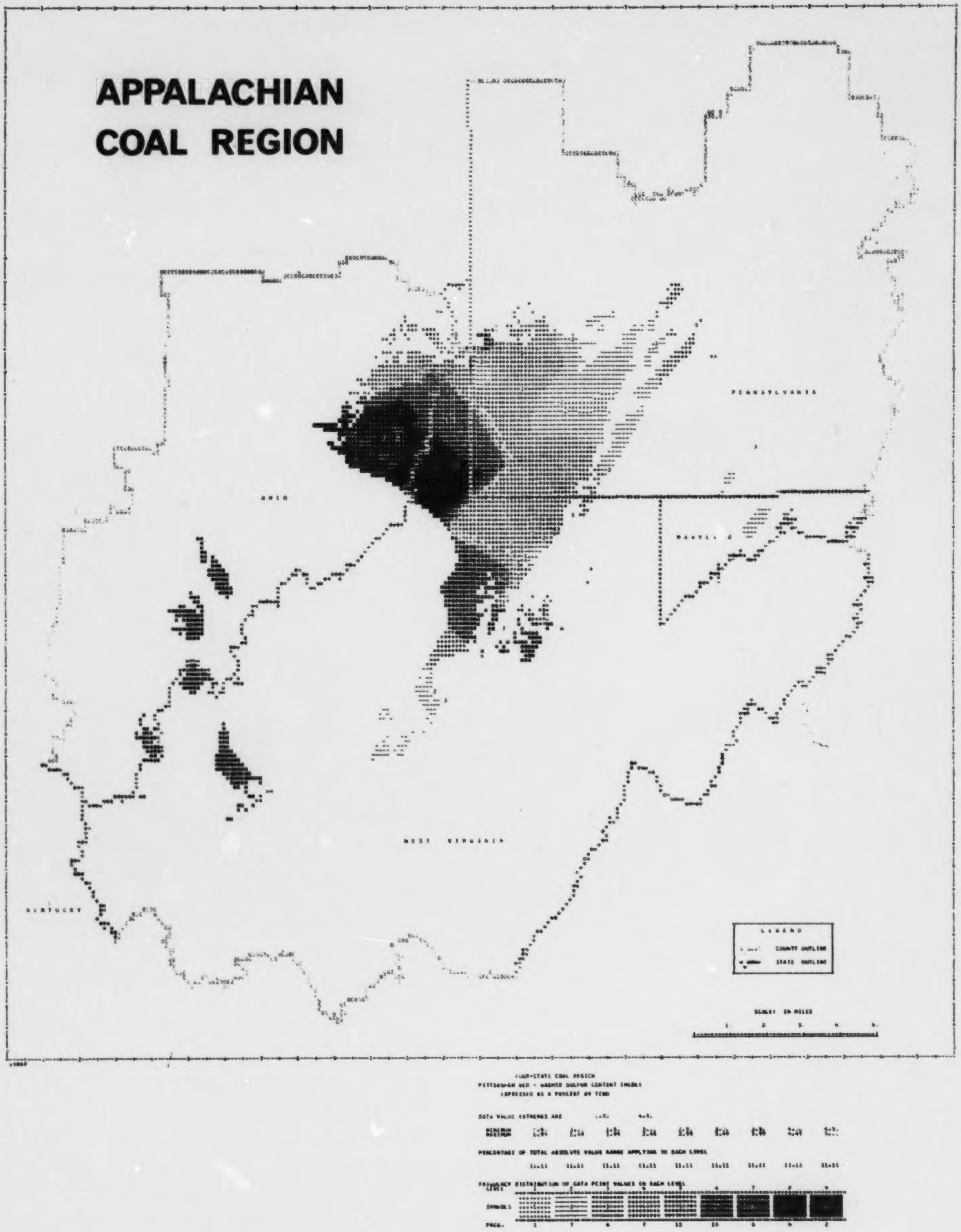

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: 16 MILES
1
2
3
4
5
FOUR-STATE COAL REGION
PITTSBURGH BED - WASHED SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
1
2
3
4
5
6
7
8
9
SYMBOLS
FREQ.
1
7
6
7
13
10
6
4
2

Figure B-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Washed Samples
(0.5% isoline interval)

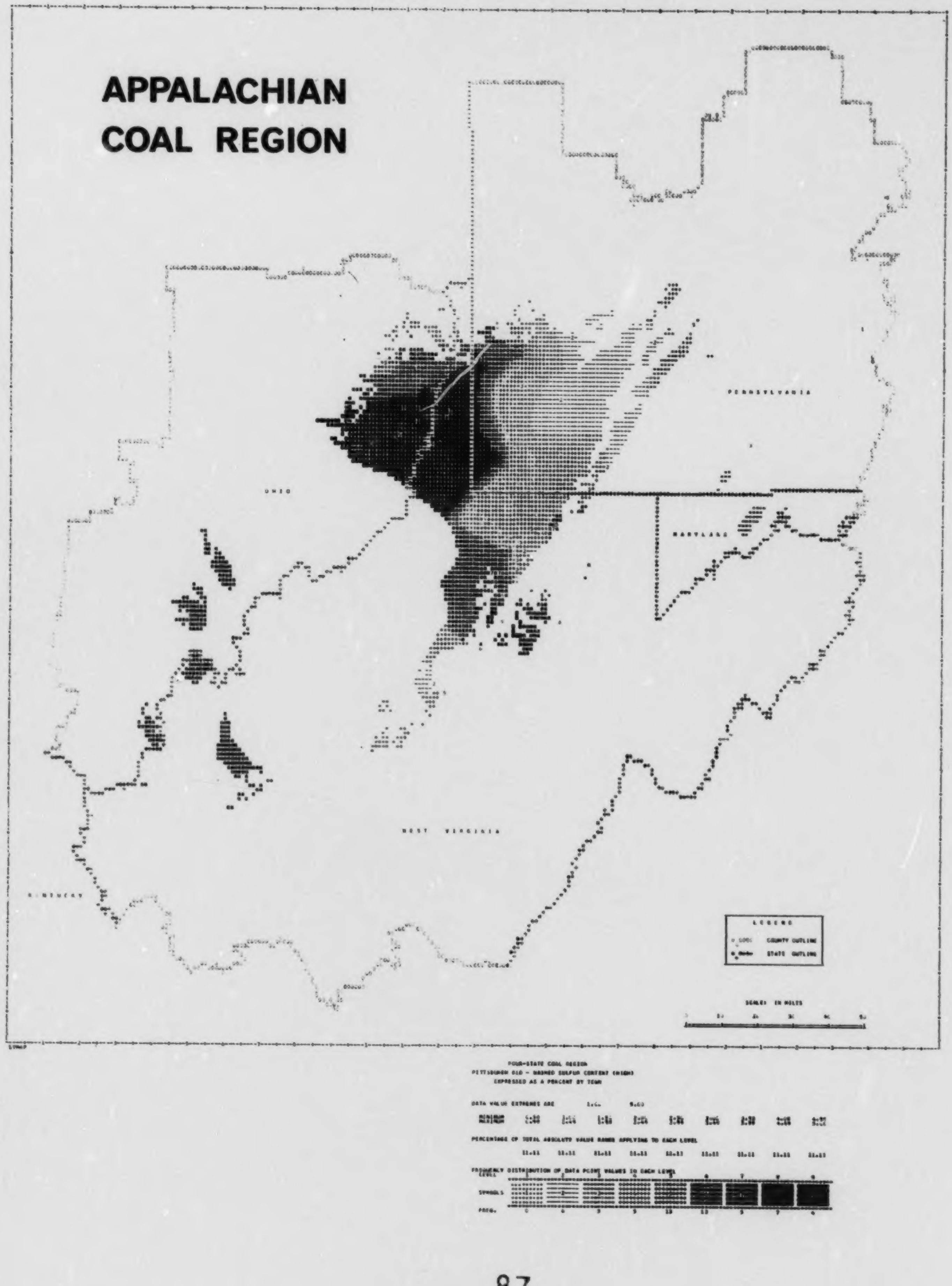

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - WASHED SULFUR CONTENT (HIGH)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL 1 2 3 4 5 6 7 8 9
SYMBOLS
FREQ. 0 4 3 5 10 13 5 7 6

Figure B-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Value for Washed Sample
(0.5% isoline interval)

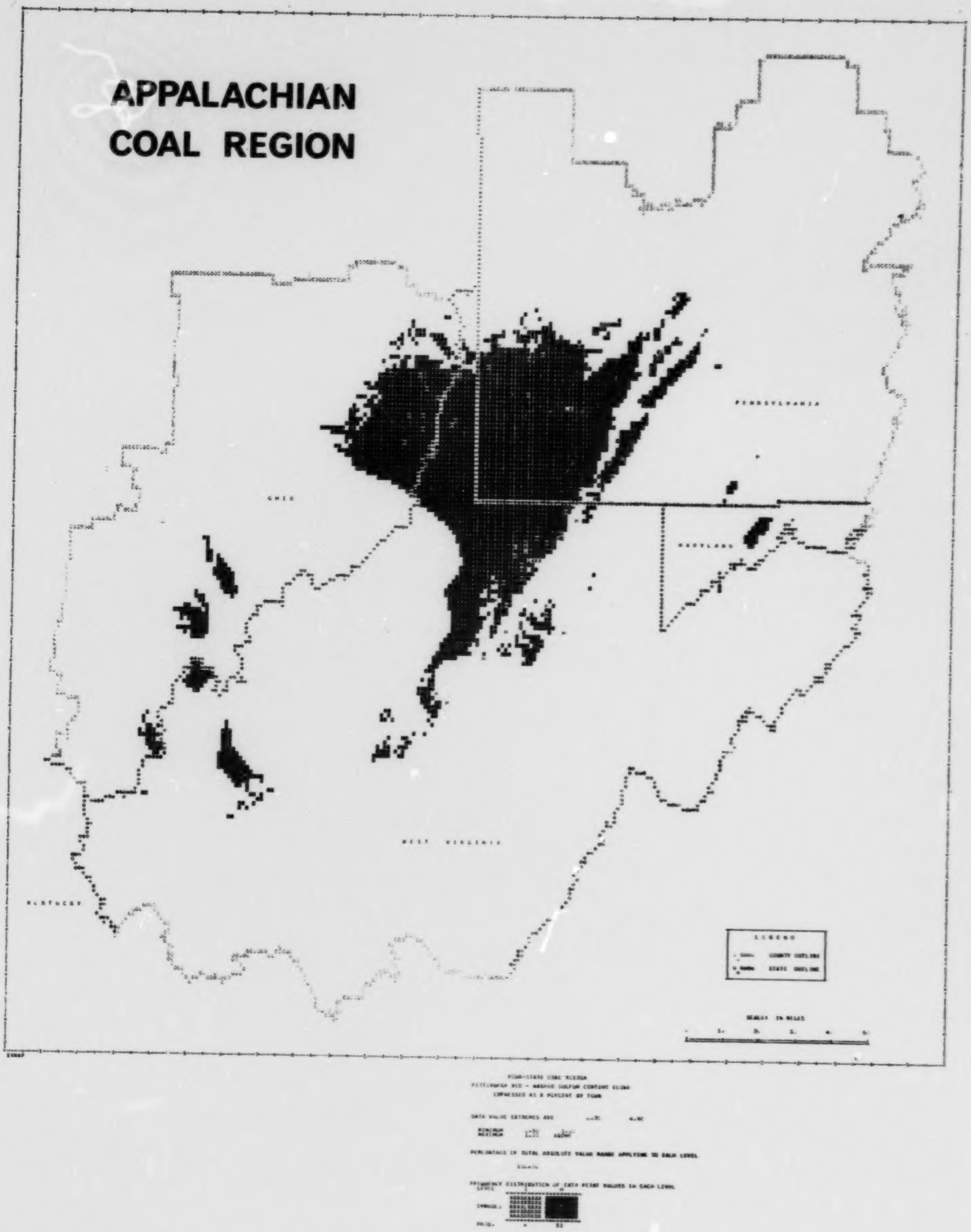

APPALACHIAN COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure B-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Washed Samples
(1% and 1/2% isolines)

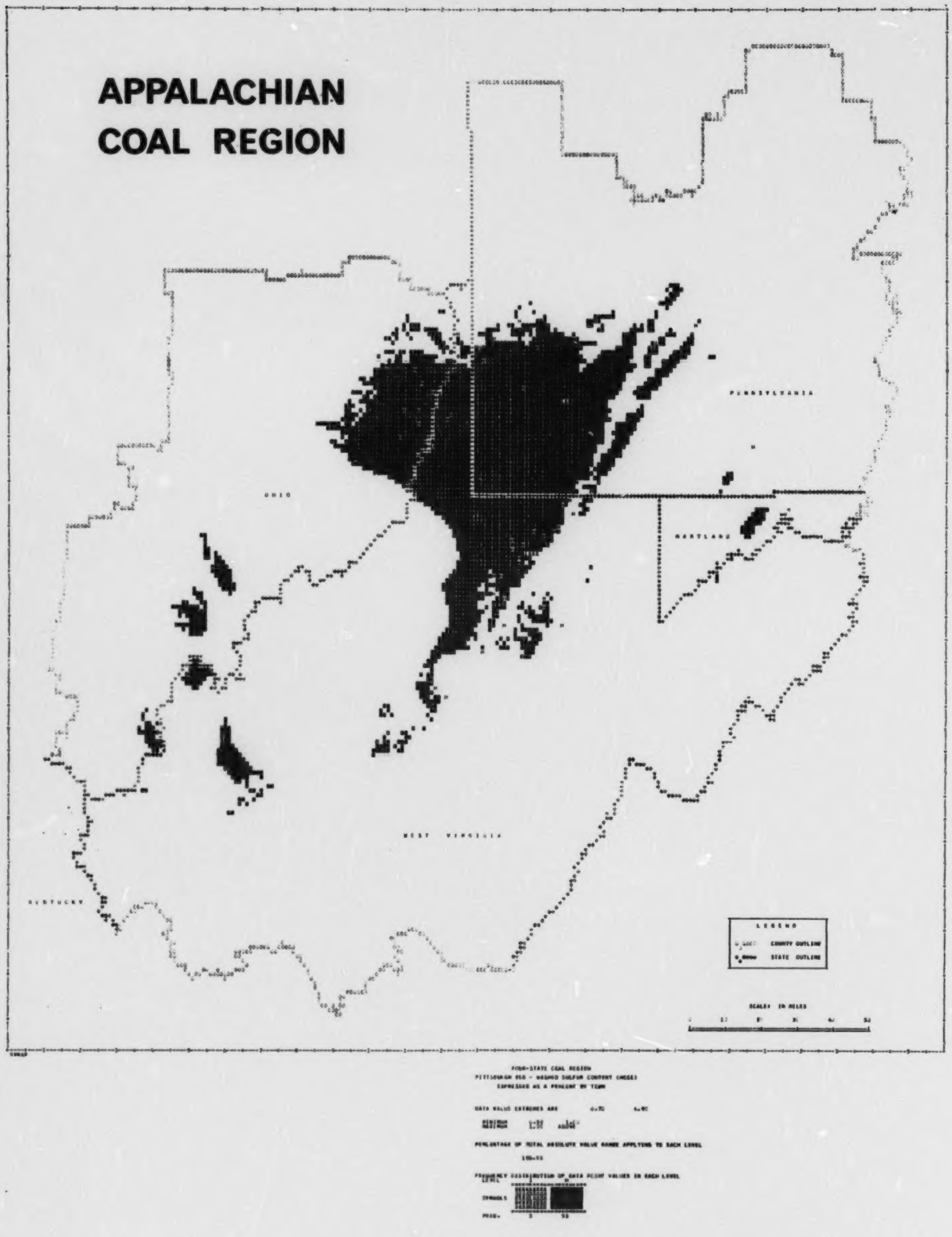

APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - WASHED SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
100.00
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.
3
93

Figure B-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Washed Samples
(1% and 1/2% isolines)

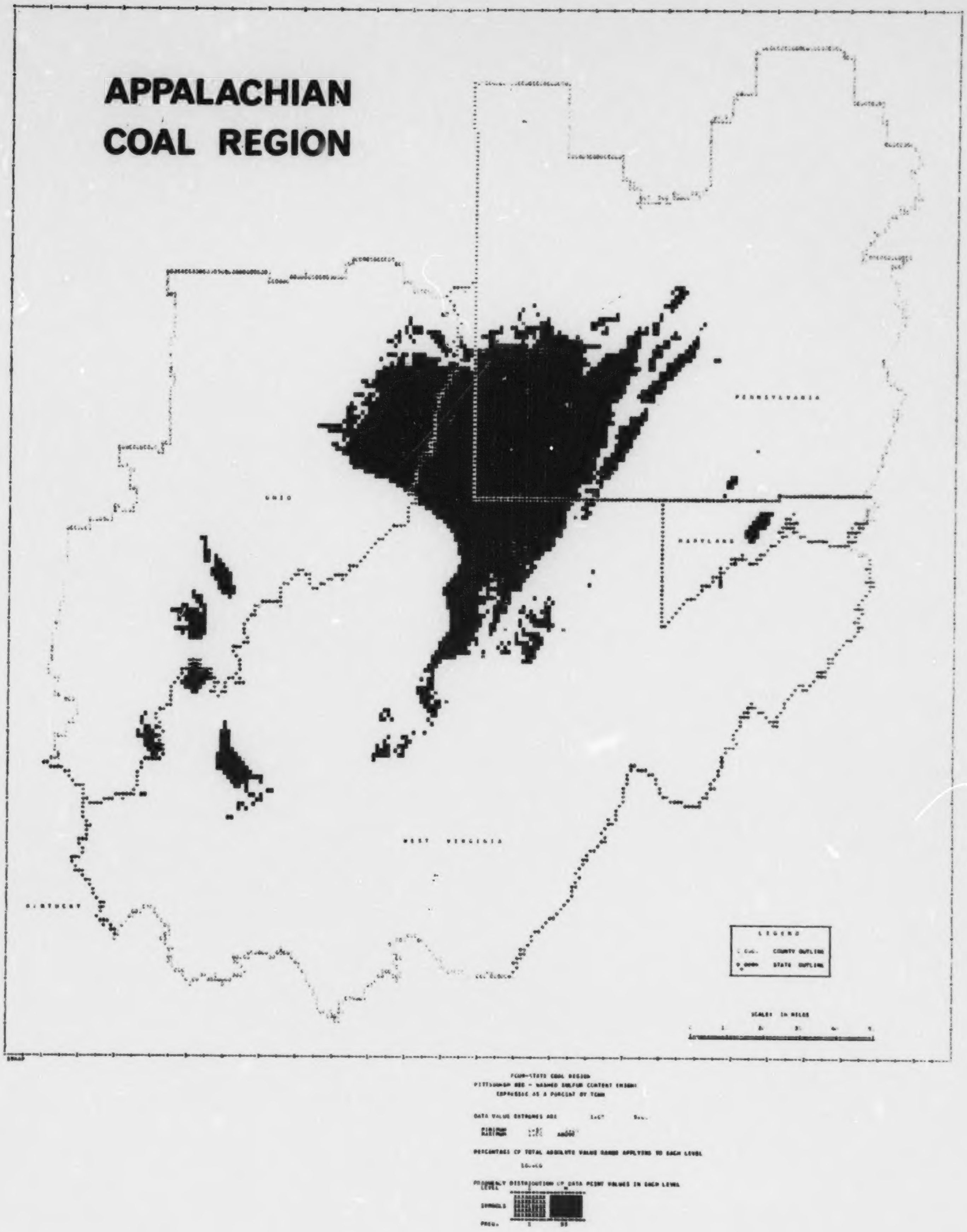
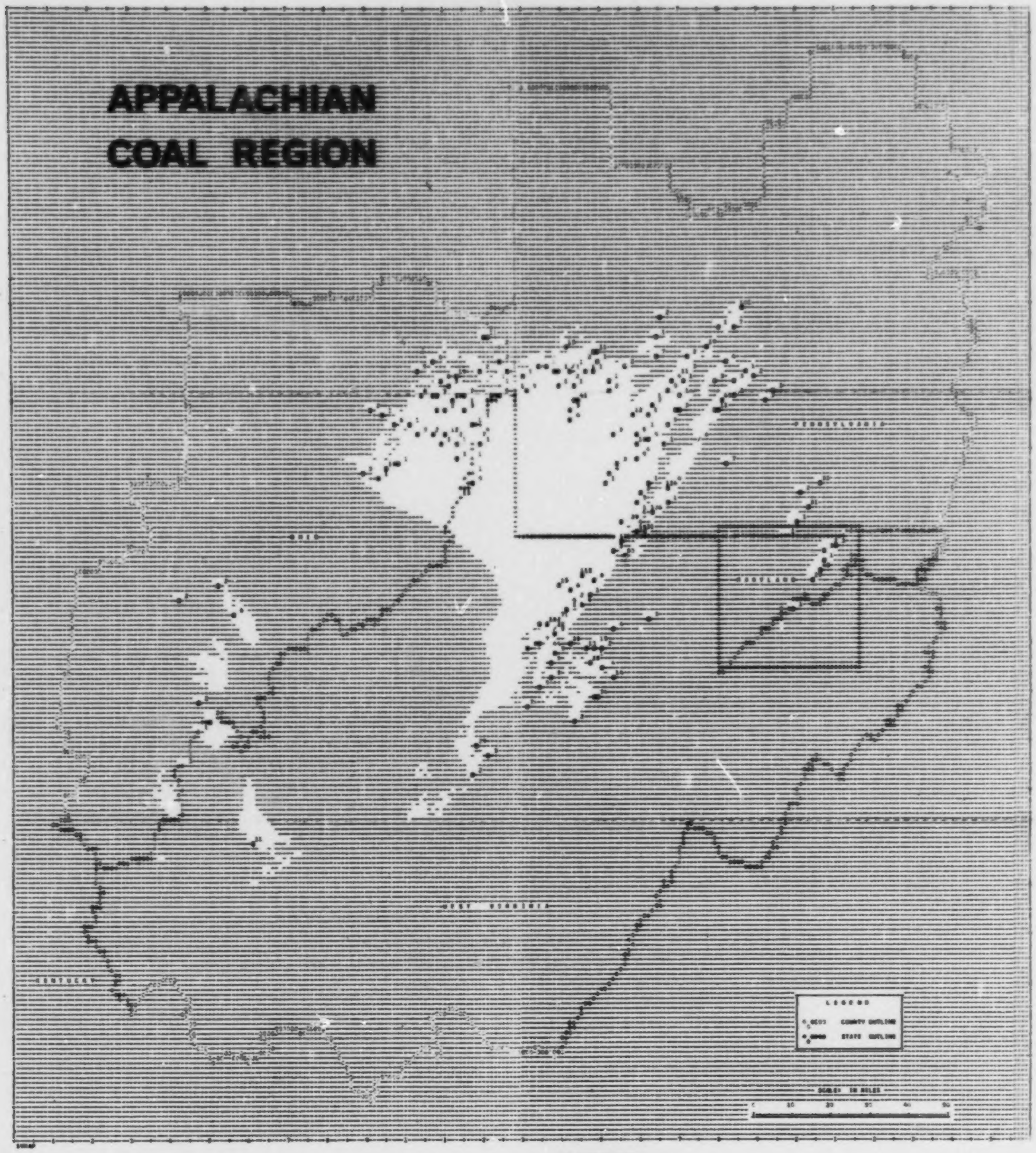

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - WASHED SULFUR CONTENT (HIGH)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure B-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Washed Samples
(1% and 1/2% isolines)


APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
10
20
30
40
50

```
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW NUMBER OF ANALYSES
    EXPRESSED AS [illegible] ABSOLUTE BY TOWN

DATA VALUE EXTREMES ARE        [illegible]        [illegible]

TOTAL SUPERIMPOSED DATA POINTS IS      6.  THESE OCCUR IN   4 LOCATIONS.

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

        100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL       1

SYMBOLS     0

FREQ.     [illegible]
```

Figure B-8
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map

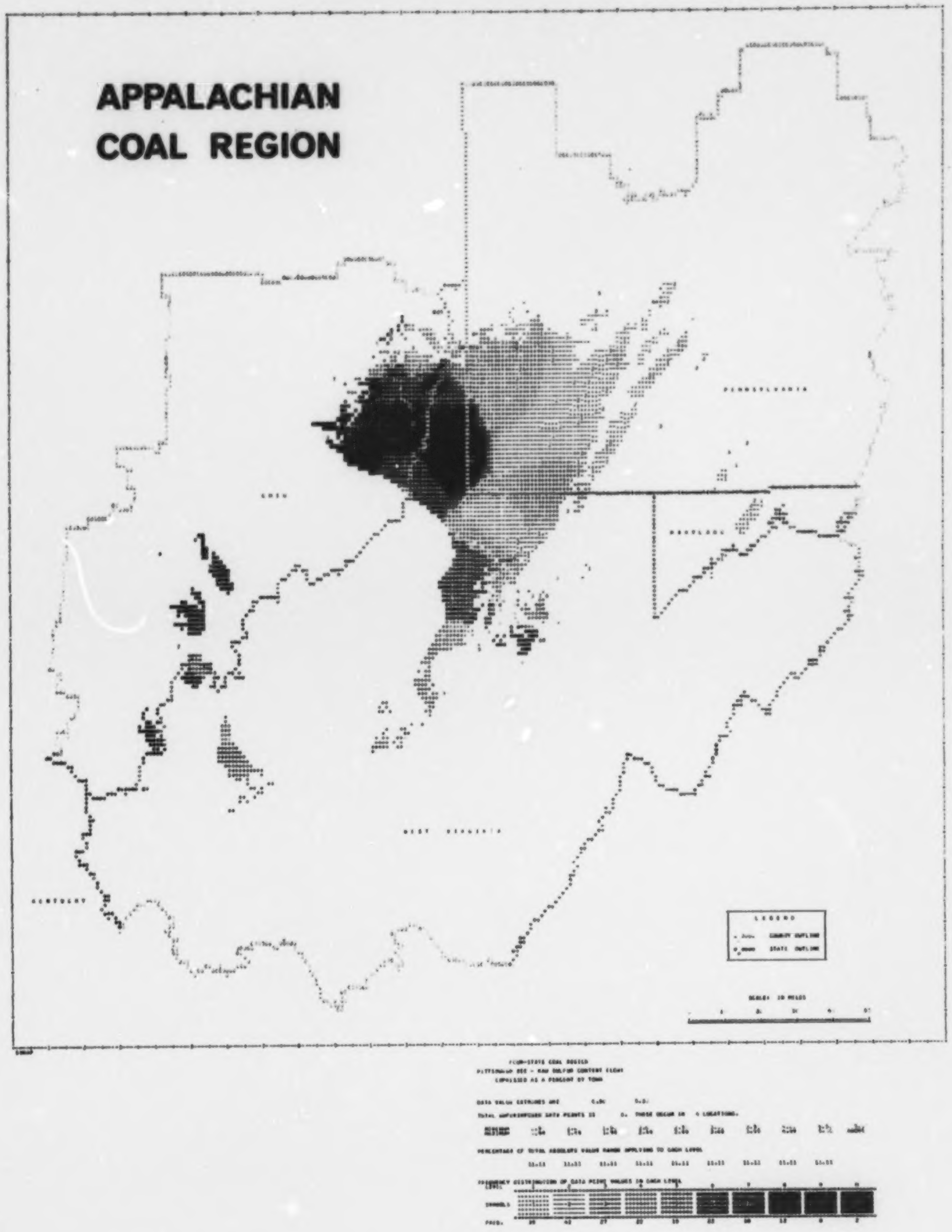

APPALACHIAN
COAL REGION
PENNSYLVANIA
WEST VIRGINIA

Figure B-9
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
(0.5% isoline interval)

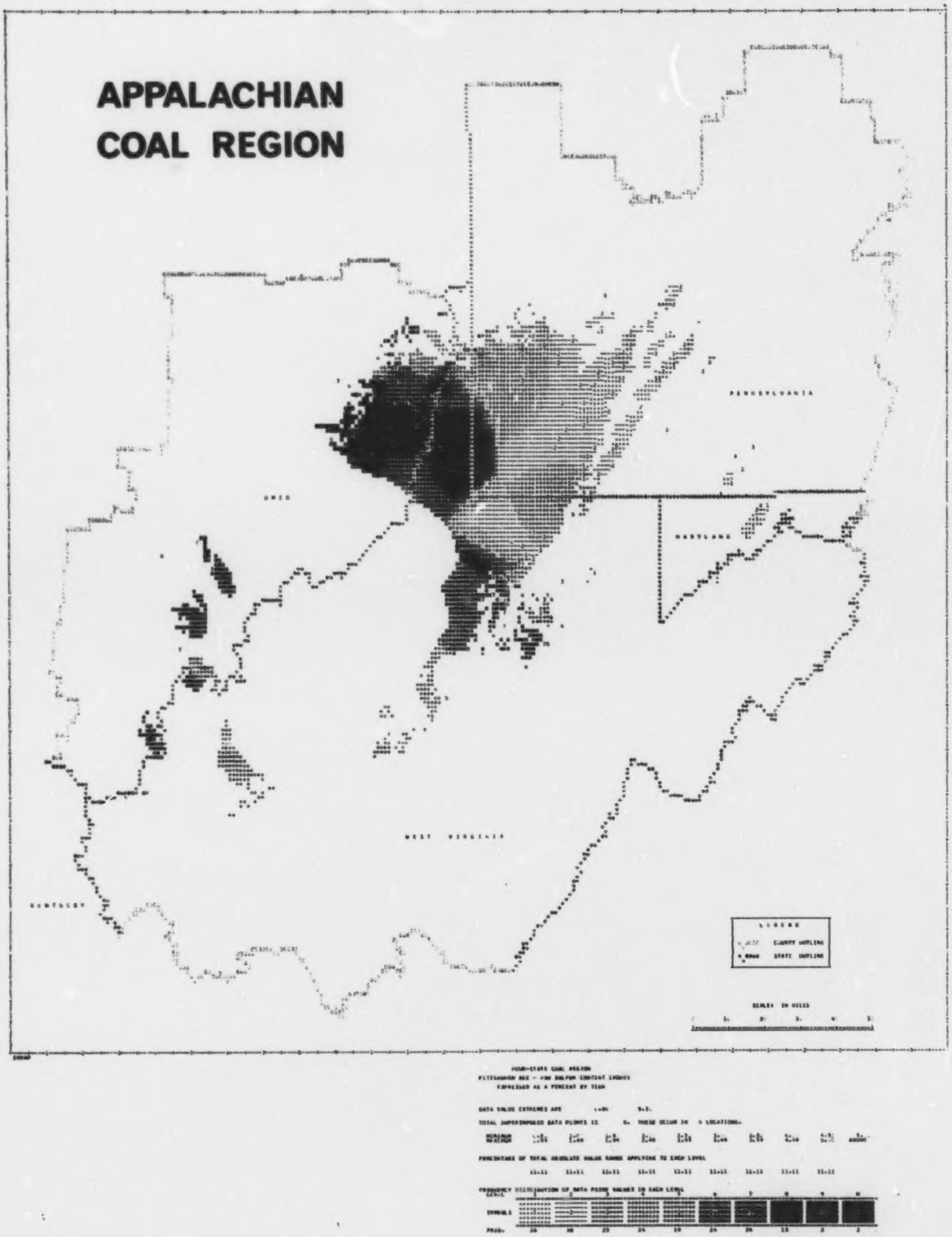

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES

Figure B-10
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(0.5% isoline interval)

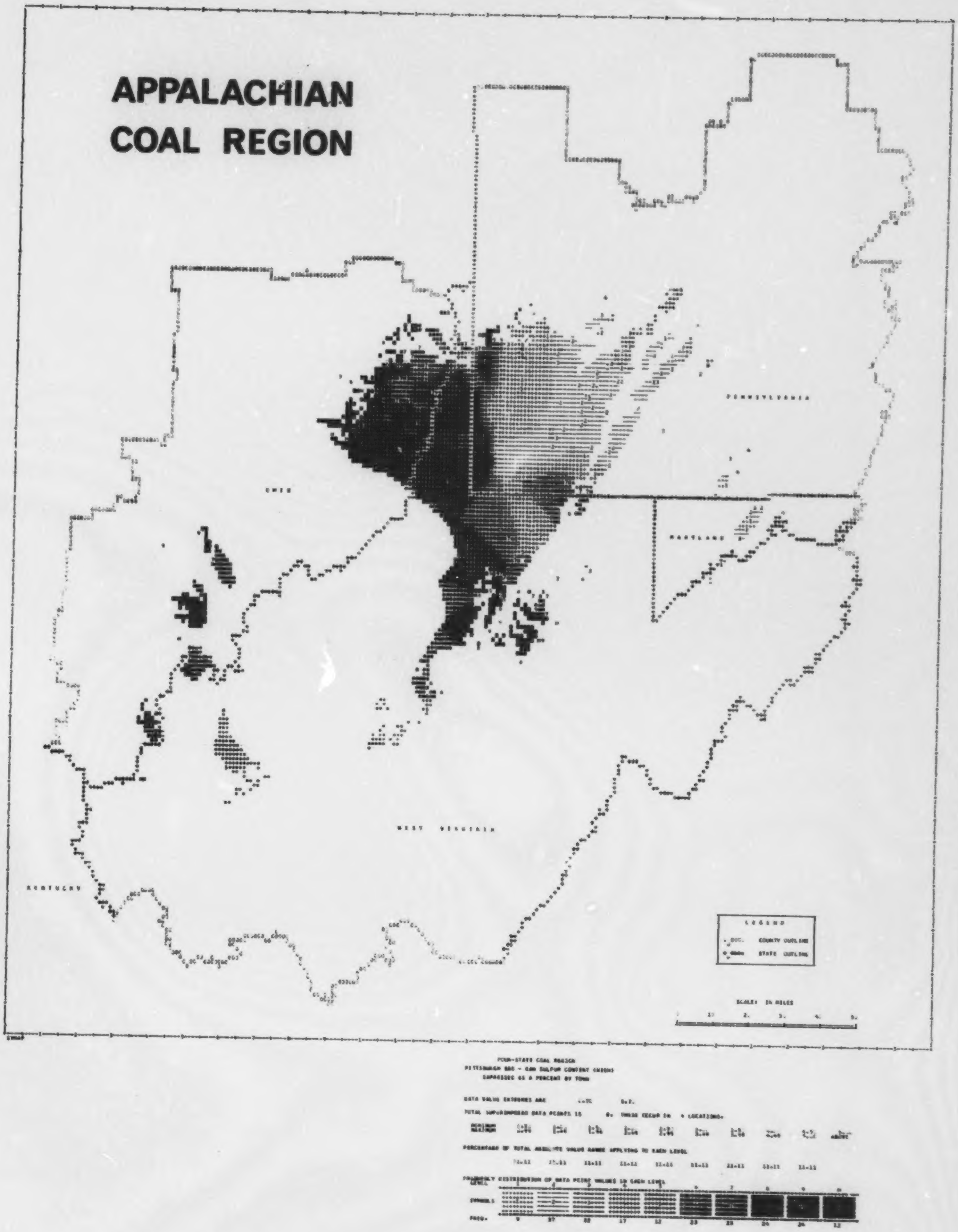

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (HIGH)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
THESE OCCUR IN
LOCATIONS.
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure B-11
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
(0.5% isoline interval)

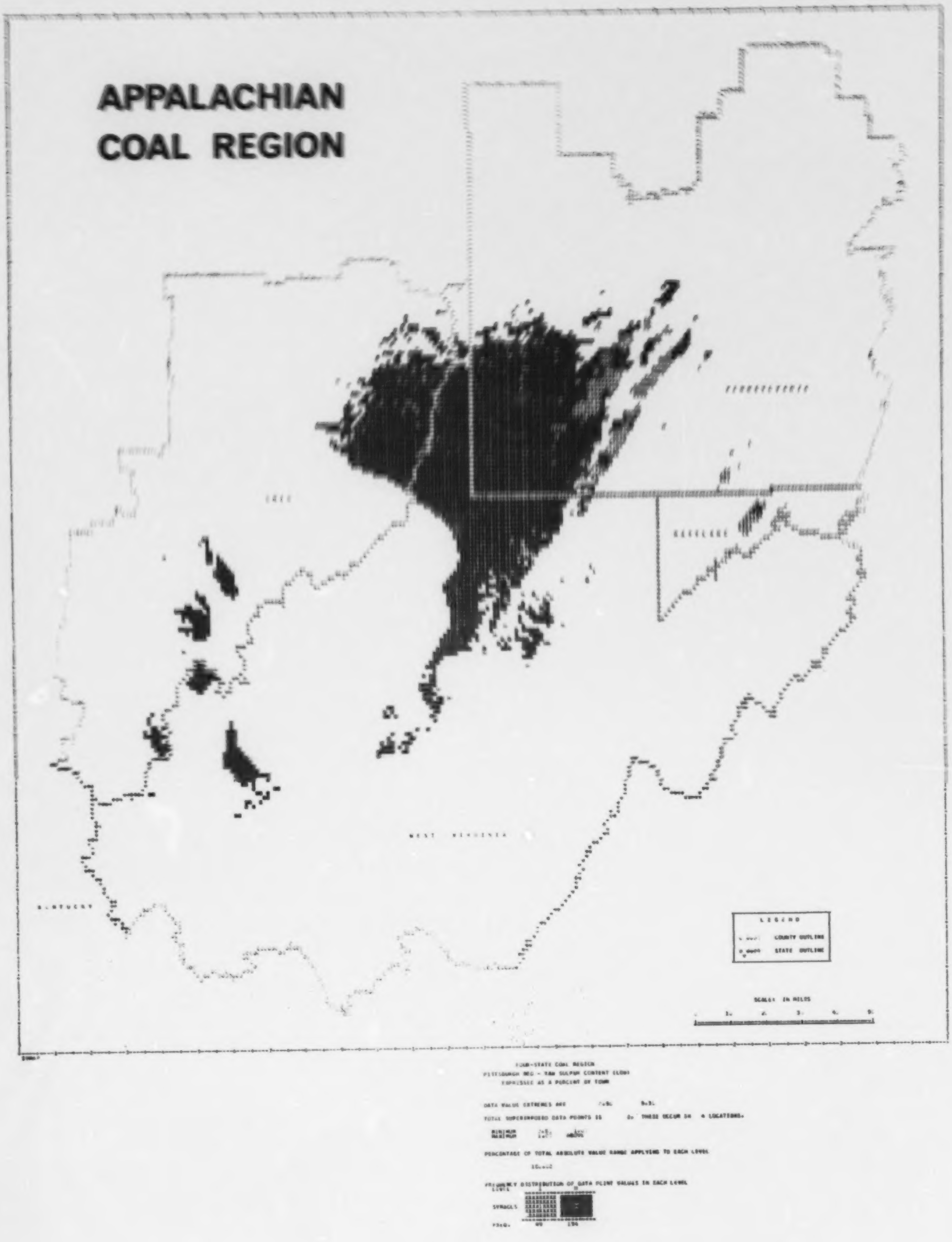

APPALACHIAN
COAL REGION
OHIO
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (LOW)
EXPRESSED AS A PERCENT OF TONS
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
THESE OCCUR IN 4 LOCATIONS.
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure B-12
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
(1% and 1/2% isolines)

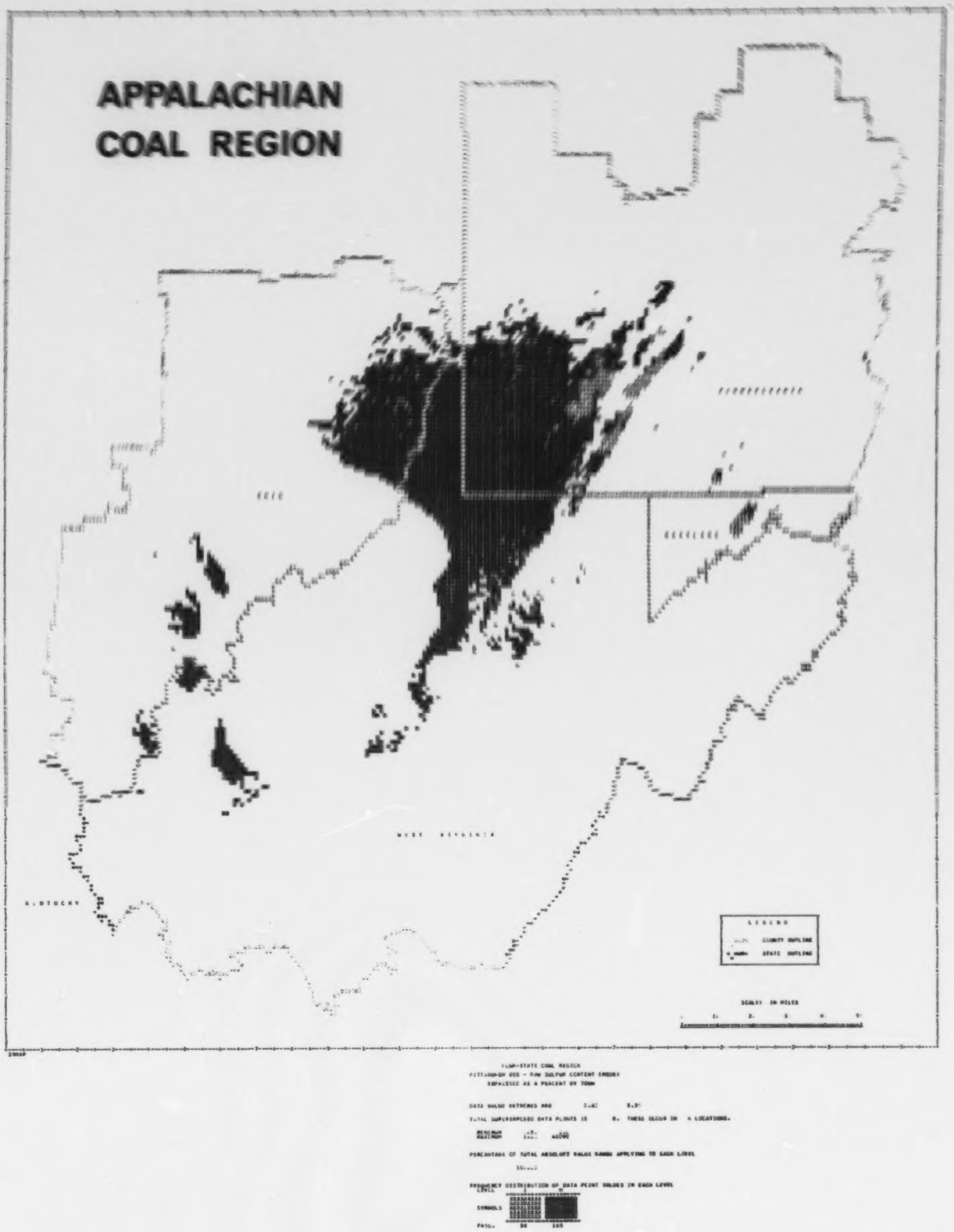

APPALACHIAN
COAL REGION
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure B-13
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(1% and 1/2% isolines)

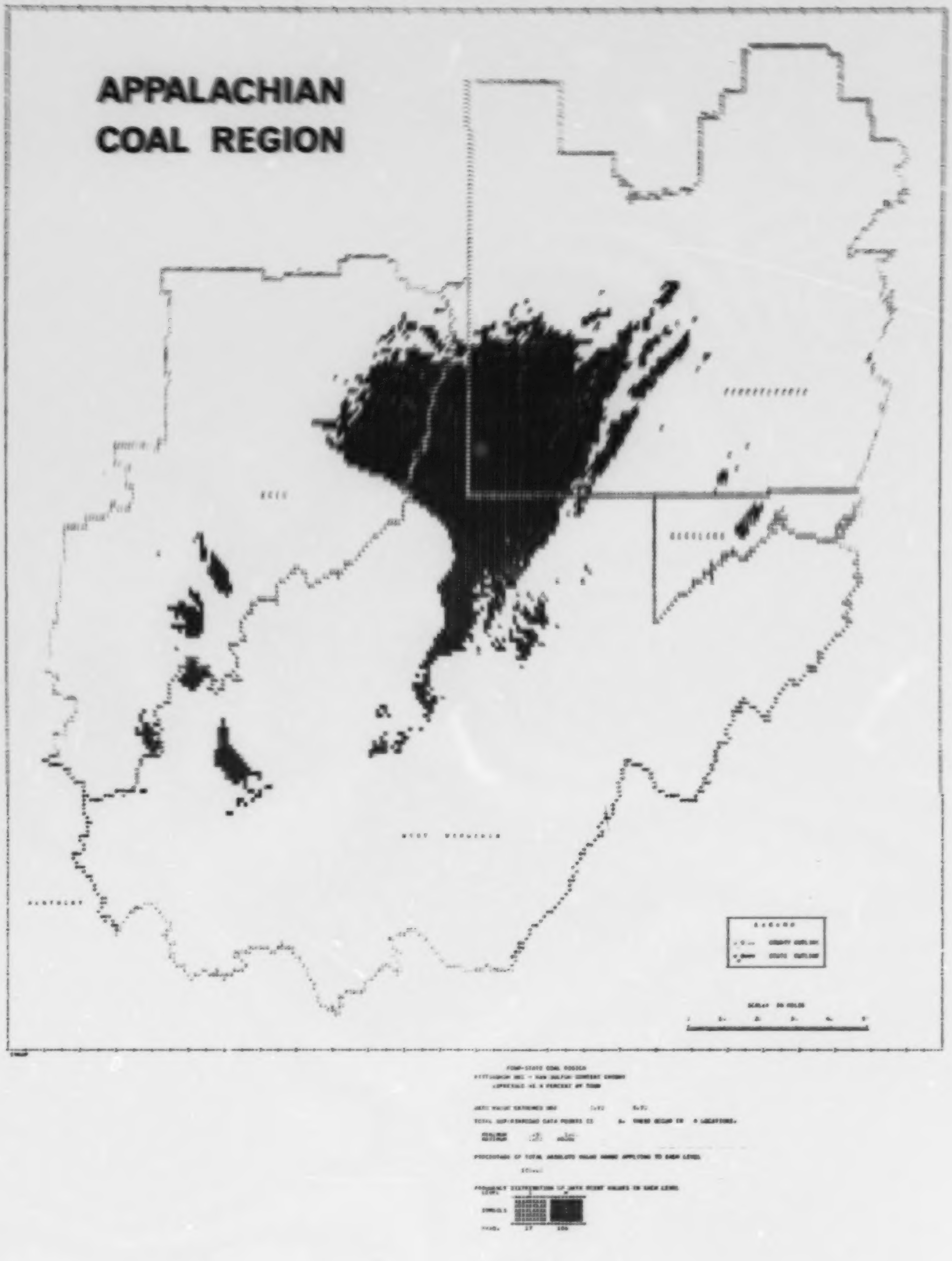
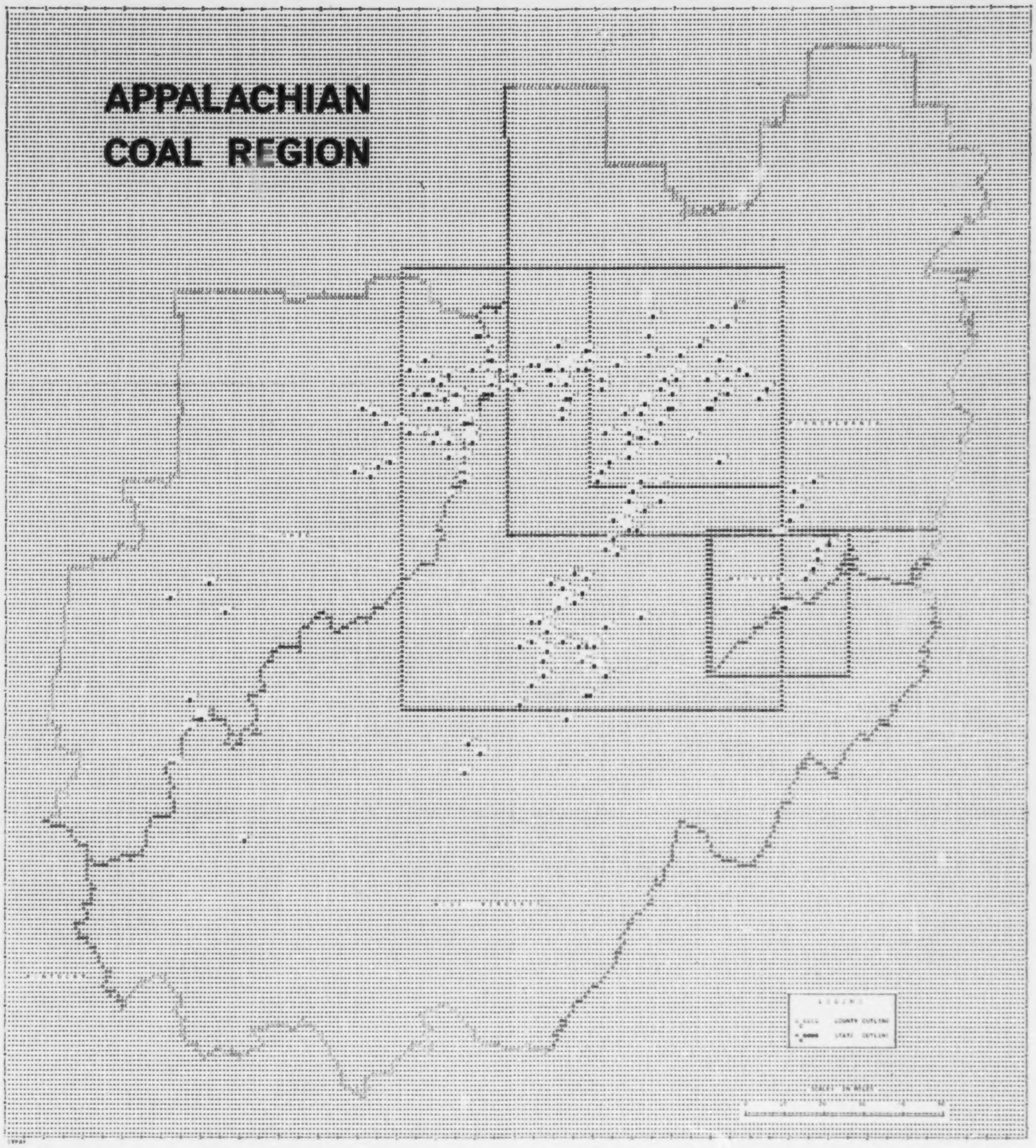

APPALACHIAN
COAL REGION

Figure B-14
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
(1% and 1/2% isolines)



```
FOUR-STATE COAL REGION
PITTSBURGH B-D - RAW NUMBER OF ANALYSIS
EXPRESSED AS AN ABSOLUTE BY TOWN

DATA VALUE EXTREMES ARE        [illegible]        [illegible]

TOTAL SUPERIMPOSED DATA POINTS IS       [illegible]   THESE OCCUR IN   [illegible] LOCATIONS.

  MINIMUM      [illegible]
  MAXIMUM      [illegible]

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

          100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL

  SYMBOLS

  FREQ.       [illegible]
```

Figure B-15
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map - 5 Mile Search Radius

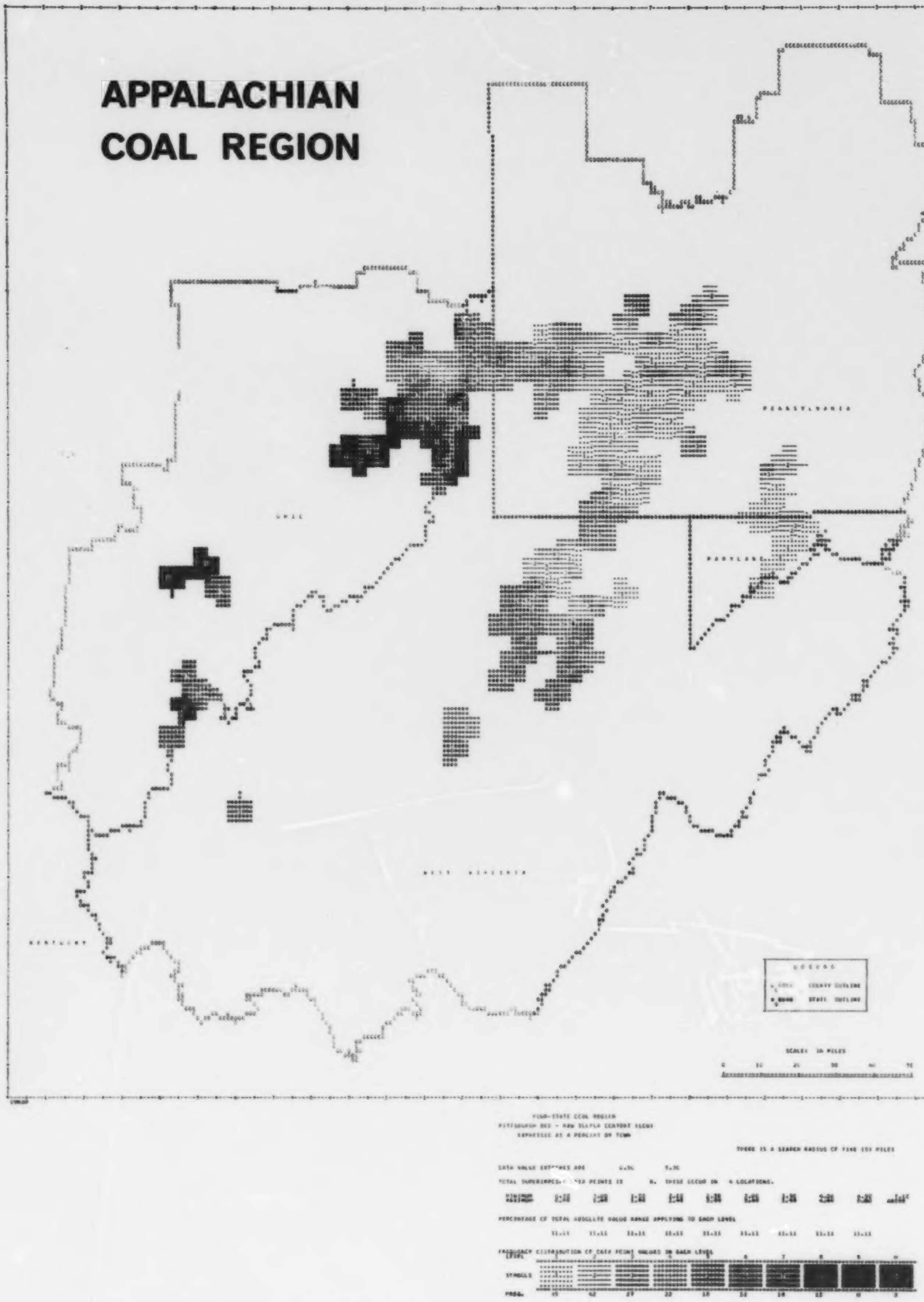

APPALACHIAN
COAL REGION
PENNSYLVANIA
MARYLAND
OHIO
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (LOW)
EXPRESSED AS A PERCENT BY TOWN
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure B-16
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
5 Mile Search Radius

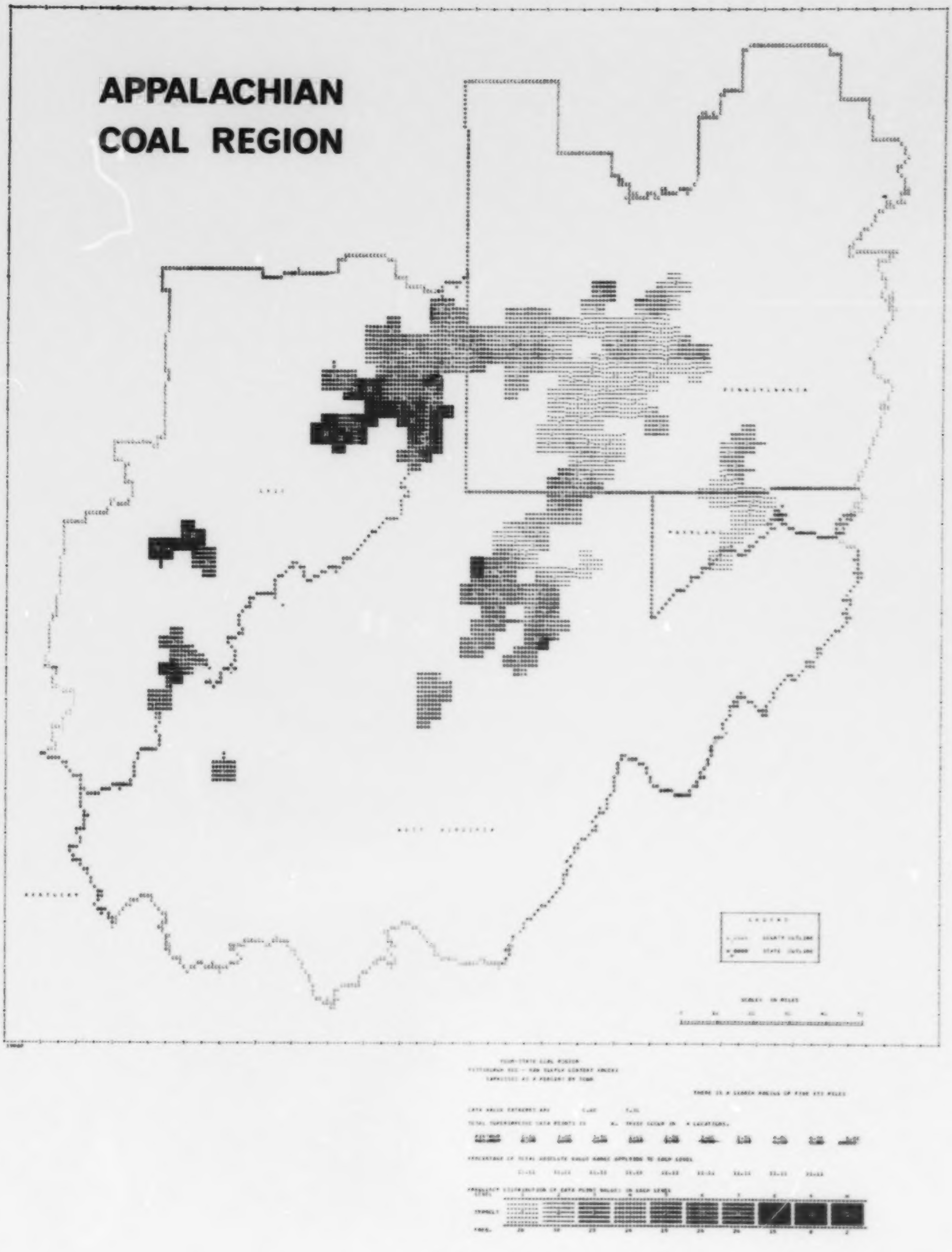

APPALACHIAN
COAL REGION

Figure B-17
Pittsburgh Coal Bed
Sulfur Conten Mapped by Towns
Mode Values for Raw Samples
5 Mile Search Radius

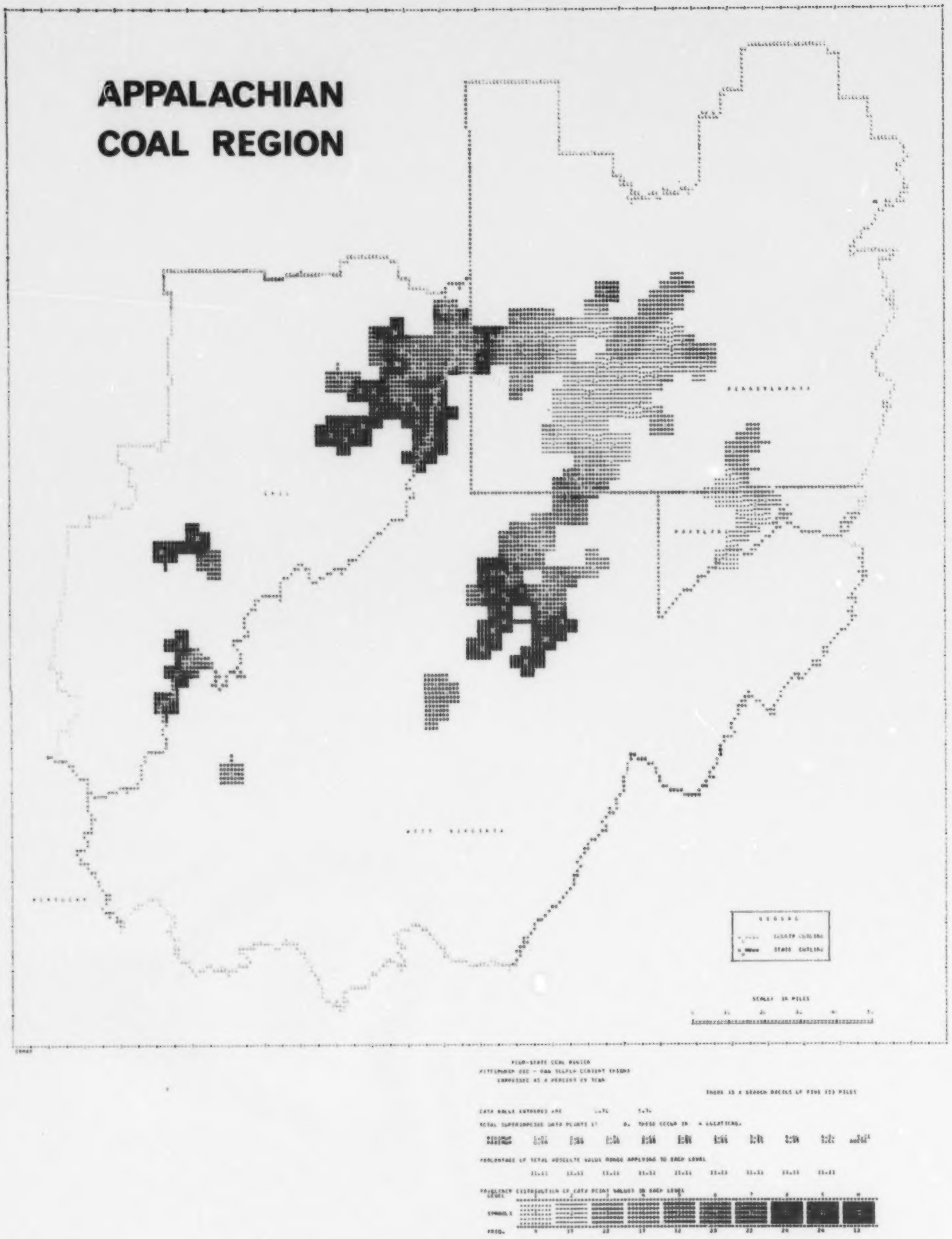

APPALACHIAN
COAL REGION
SCALE: IN MILES
LEVEL
SYMBOLS
FREQ.

Figure B-18
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
5 Mile Search Radius

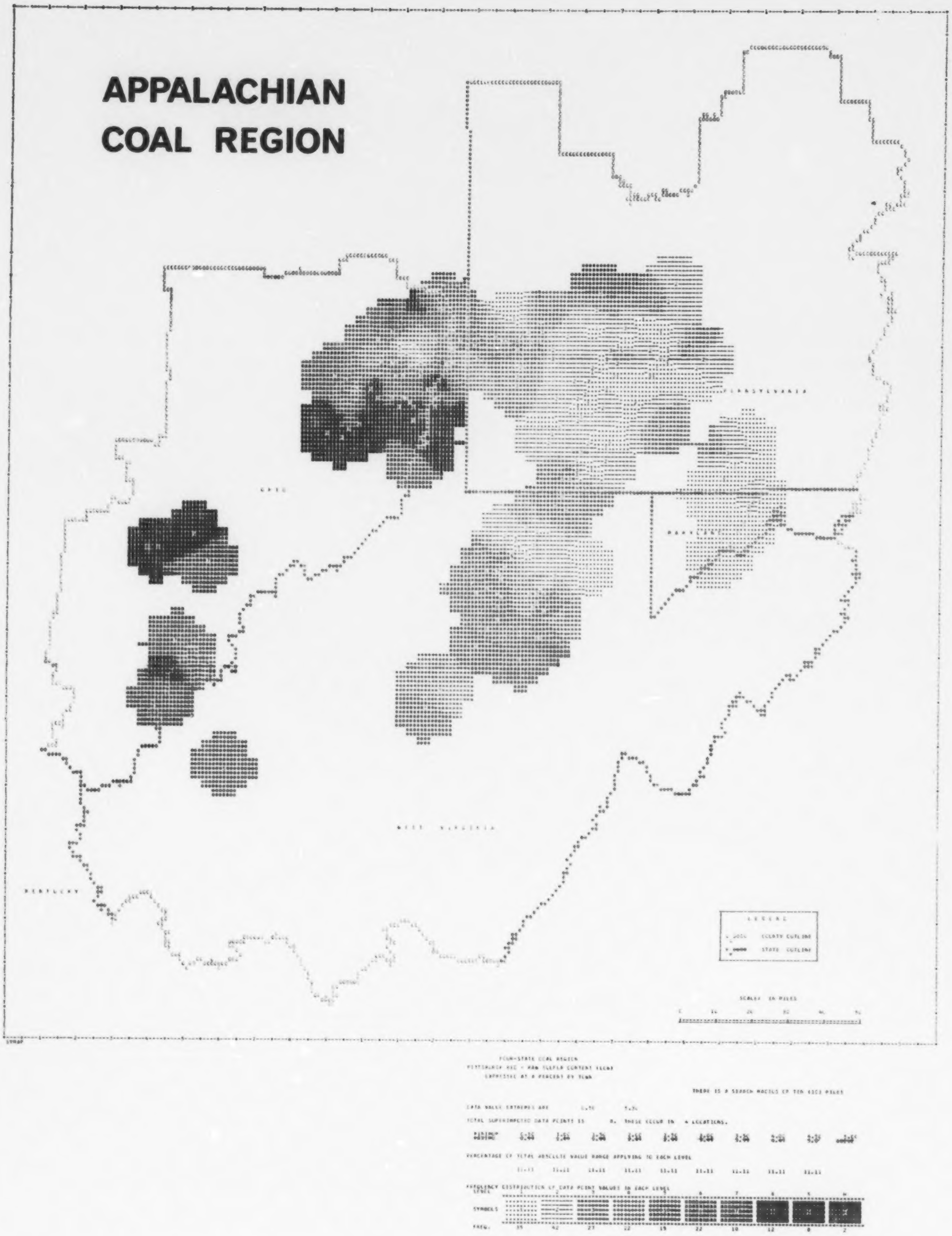

APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
10
20
30
40
50
FOUR-STATE COAL REGION
THERE IS A SEARCH RADIUS OF TEN (10) MILES
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
THESE OCCUR IN 4 LOCATIONS.
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
1
2
3
4
5
6
7
8
9
10
SYMBOLS
FREQ.
35
42
27
22
19
22
10
12
8
2

Figure B-19
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
10 Mile Search Radius

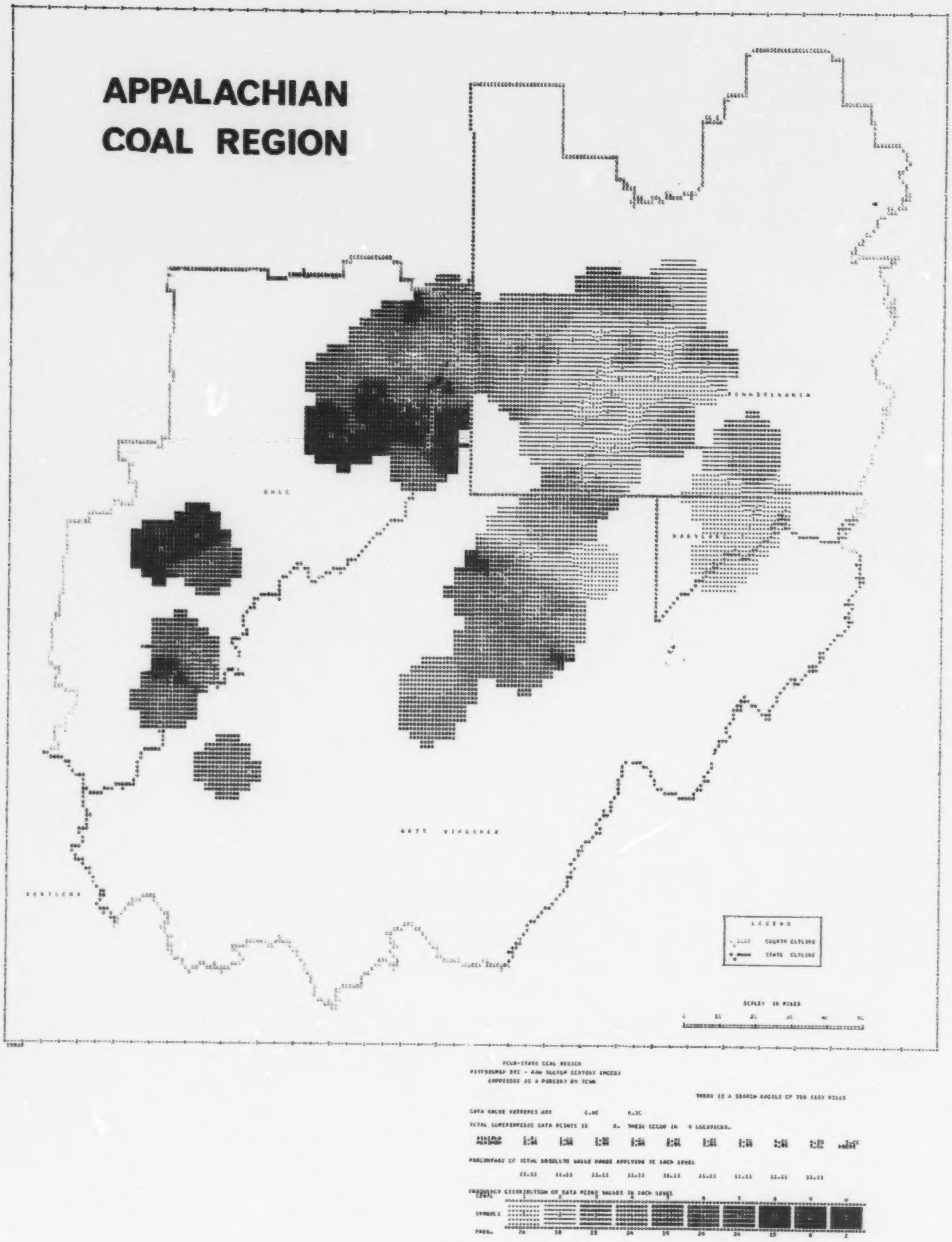

APPALACHIAN
COAL REGION

Figure B-20
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
10 Mile Search Radius

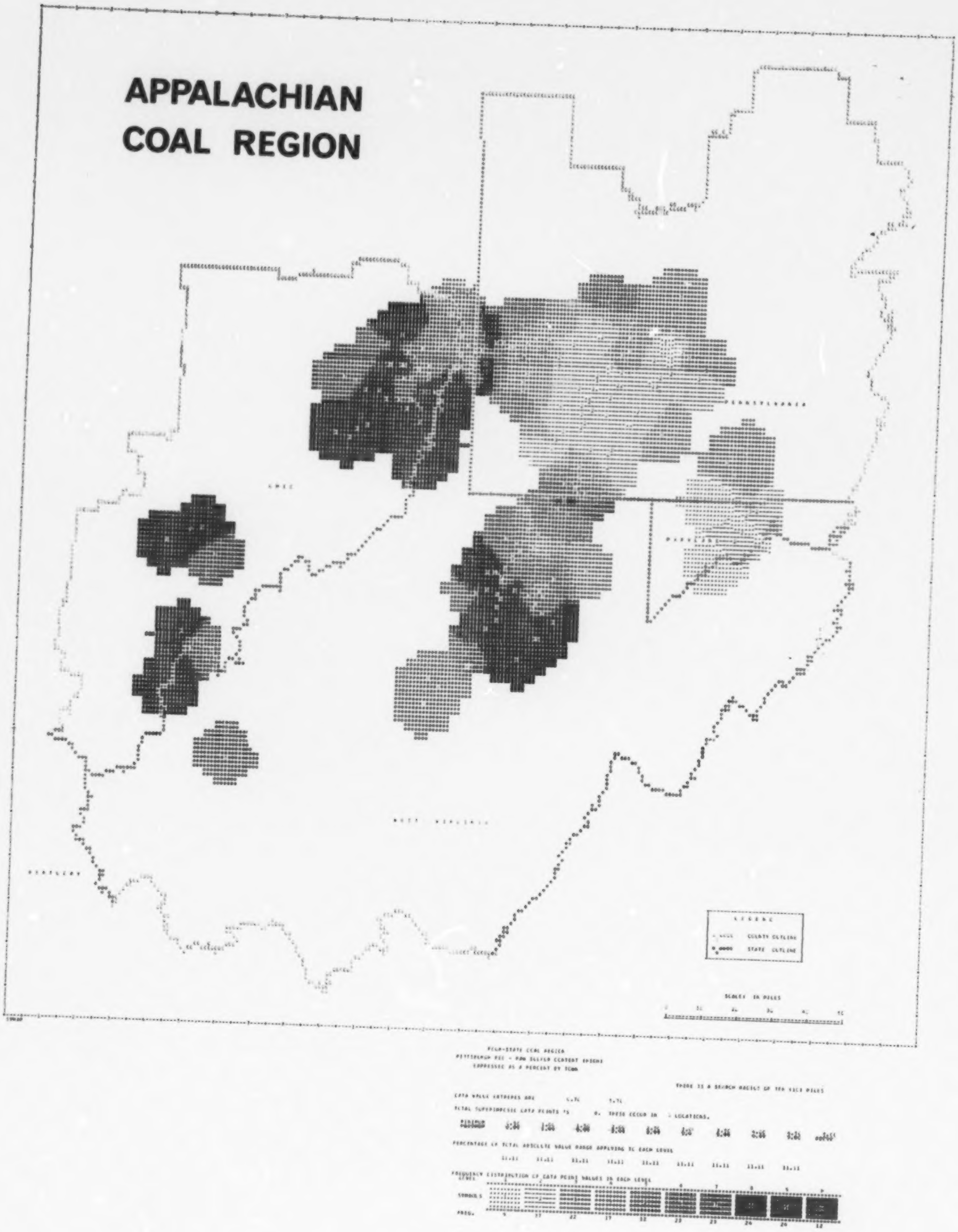
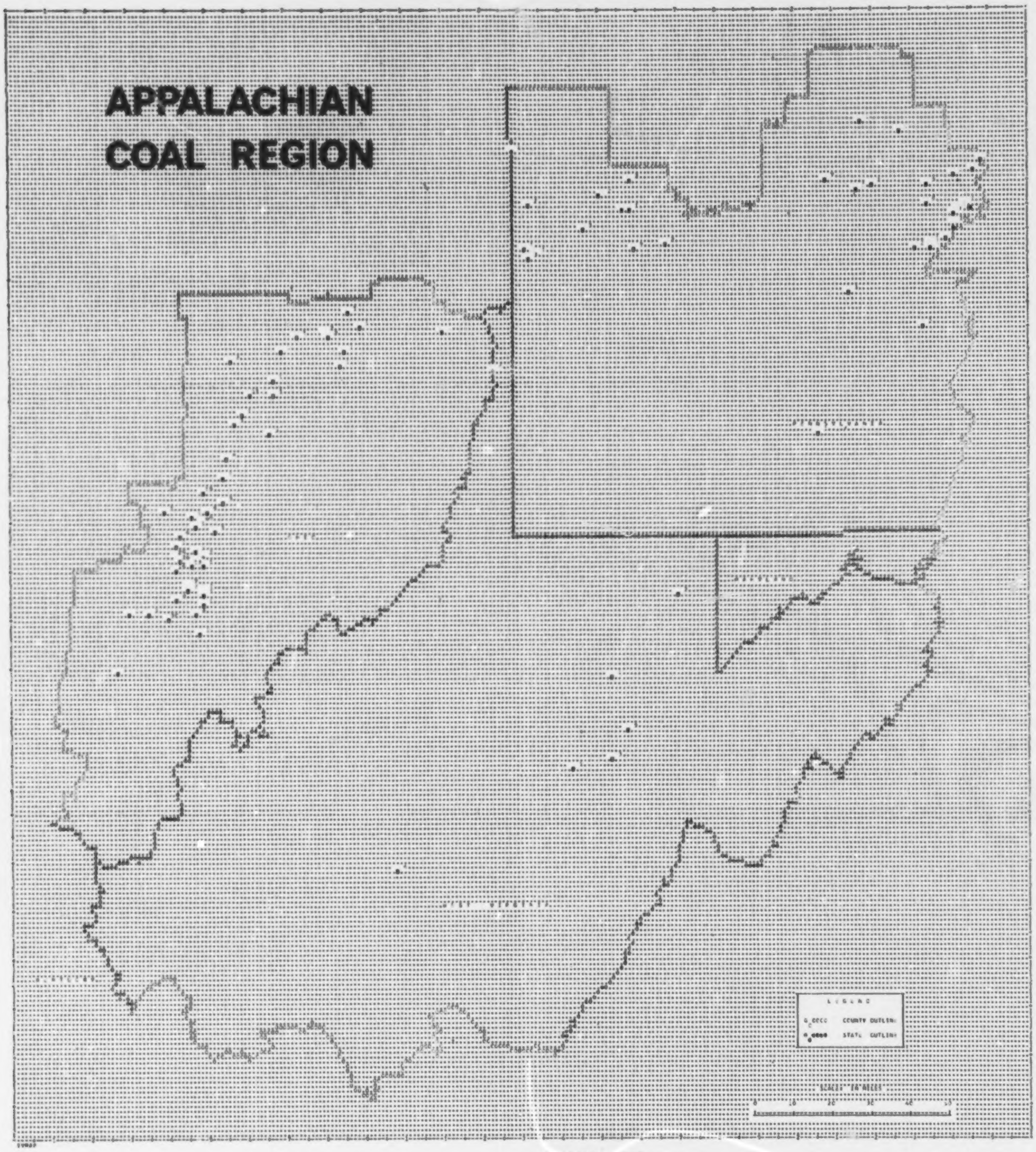

APPALACHIAN
COAL REGION
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES

Figure B-21
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
10 Mile Search Radius


APPALACHIAN
COAL REGION
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
10
20
30
40
50

```
        FOUR-STATE COAL REGION
MIDDLE KITTANNING BED - RAW NUMBER OF ANALYSES
    EXPRESSED AS AN ABSOLUTE BY TOWN

DATA VALUE EXTREMES ARE        0.0        0.0
TOTAL SUPERIMPOSED DATA POINTS IS      2.  THESE OCCUR IN   1 LOCATIONS.

 MINIMUM    0.0
 MAXIMUM    0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

          100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL          1

 SYMBOLS

 FREQ.         90
```

Figure C-1
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map - 5 Mile Search Radius

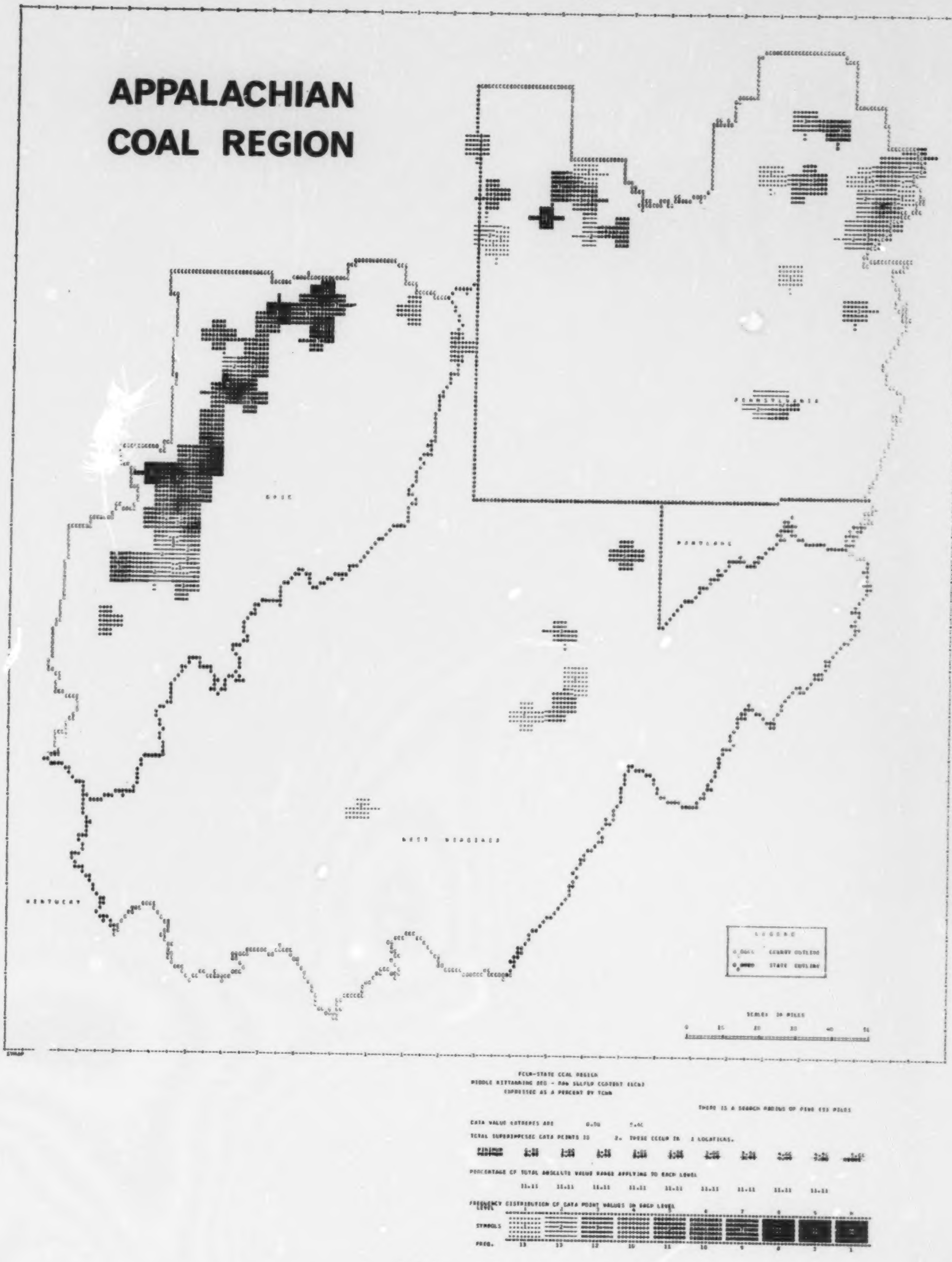
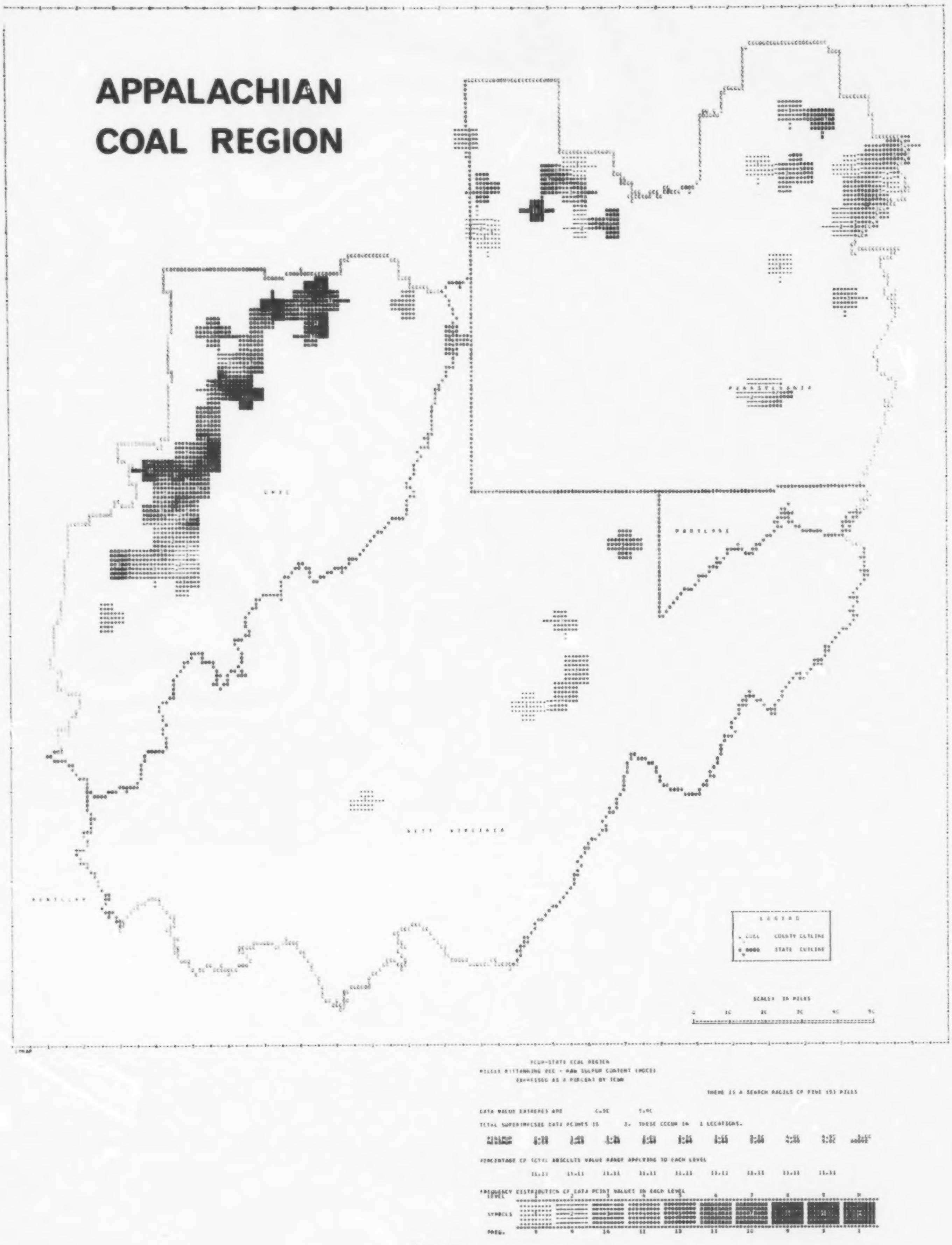

APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: 10 MILES
0 10 20 30 40 50
FOUR-STATE COAL REGION
MIDDLE KITTANNING BED - RAW SULFUR CONTENT (LOW)
EXPRESSED AS A PERCENT BY TOWN
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS 2. THESE OCCUR IN 1 LOCATIONS.
MINIMUM MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL 1 2 3 4 5 6 7 8 9 10
SYMBOLS
FREQ. 13 13 12 10 11 10 9 8 3 1

Figure C-2
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
5 Mile Search Radius


APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
10
20
30
40
50

```
FOUR-STATE COAL REGION
MIDDLE KITTANNING BED - RAW SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
                                        THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE        0.50        5.00
TOTAL SUPERIMPOSED DATA POINTS IS      2.  THESE OCCUR IN   1 LOCATIONS.
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
        11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL      1       2       3       4       5       6       7       8       9       10
SYMBOLS
FREQ.      9       9      14      11      13      11      10       9       5       1
```

Figure C-3
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
5 Mile Search Radius

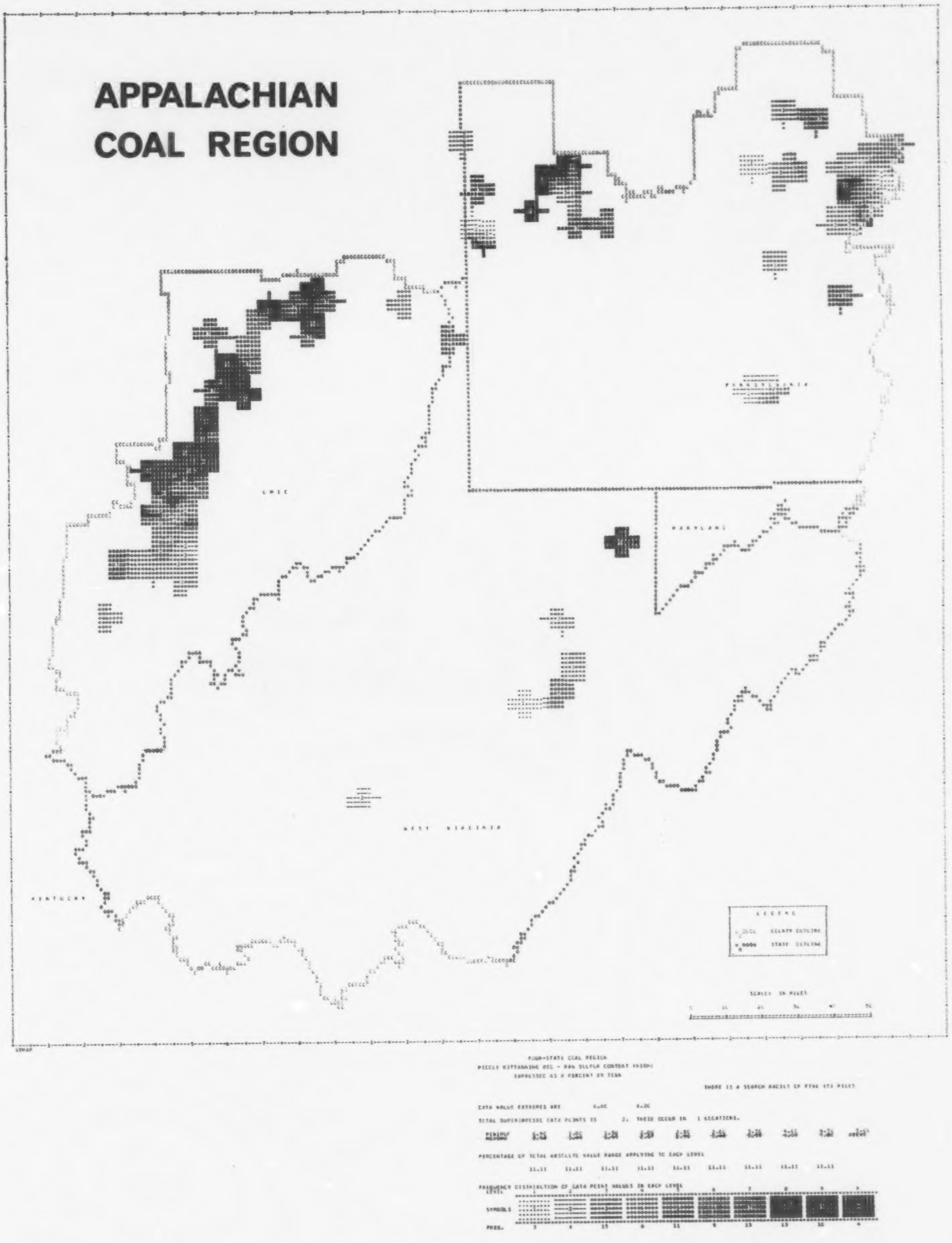

APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL 1 2 3 4 5 6 7 8 9
SYMBOLS
FREQ. 3 4 15 8 11 9 13 13 10 4

Figure C-4
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
5 Mile Search Radius

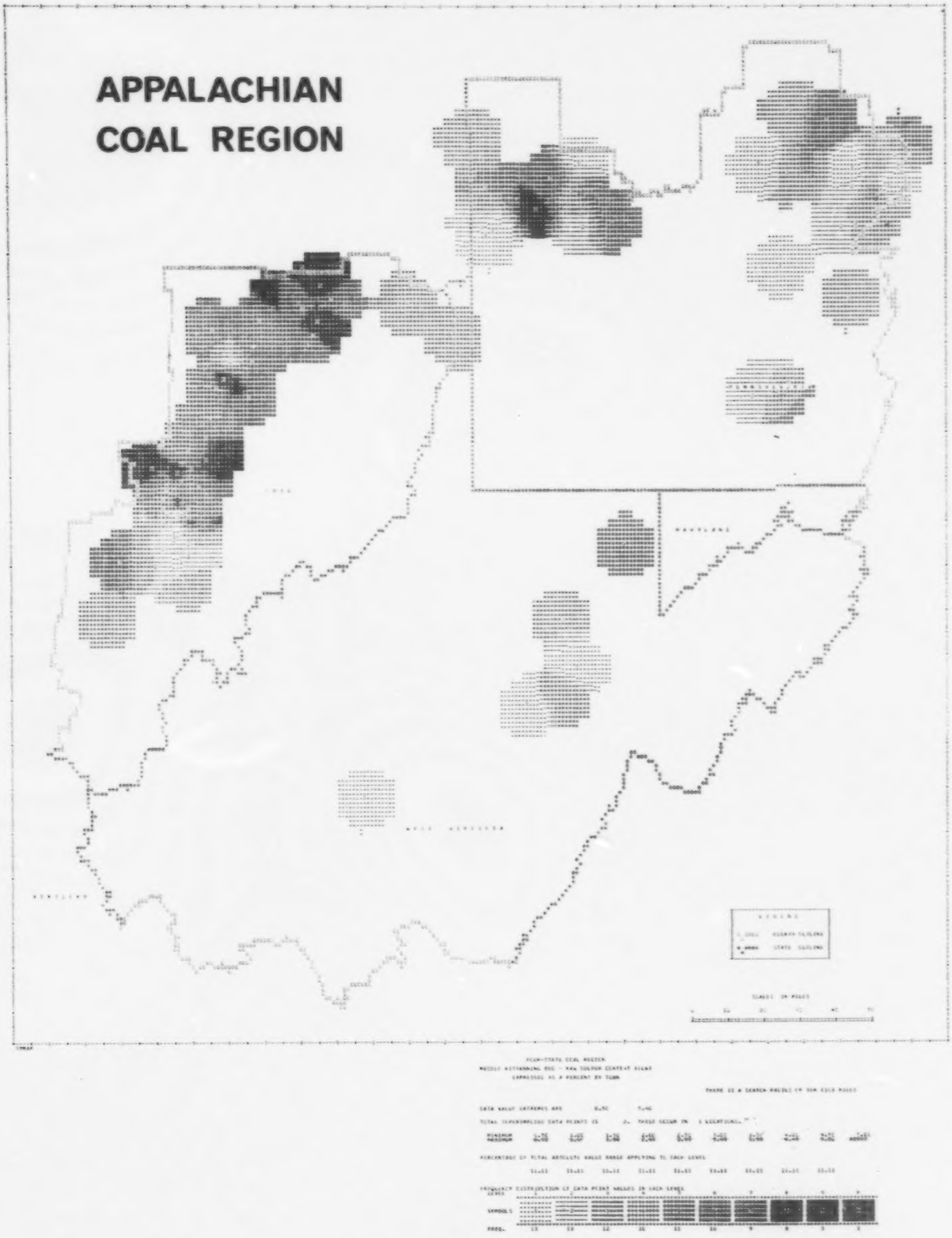

APPALACHIAN
COAL REGION

Figure C-5
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
10 Mile Search Radius

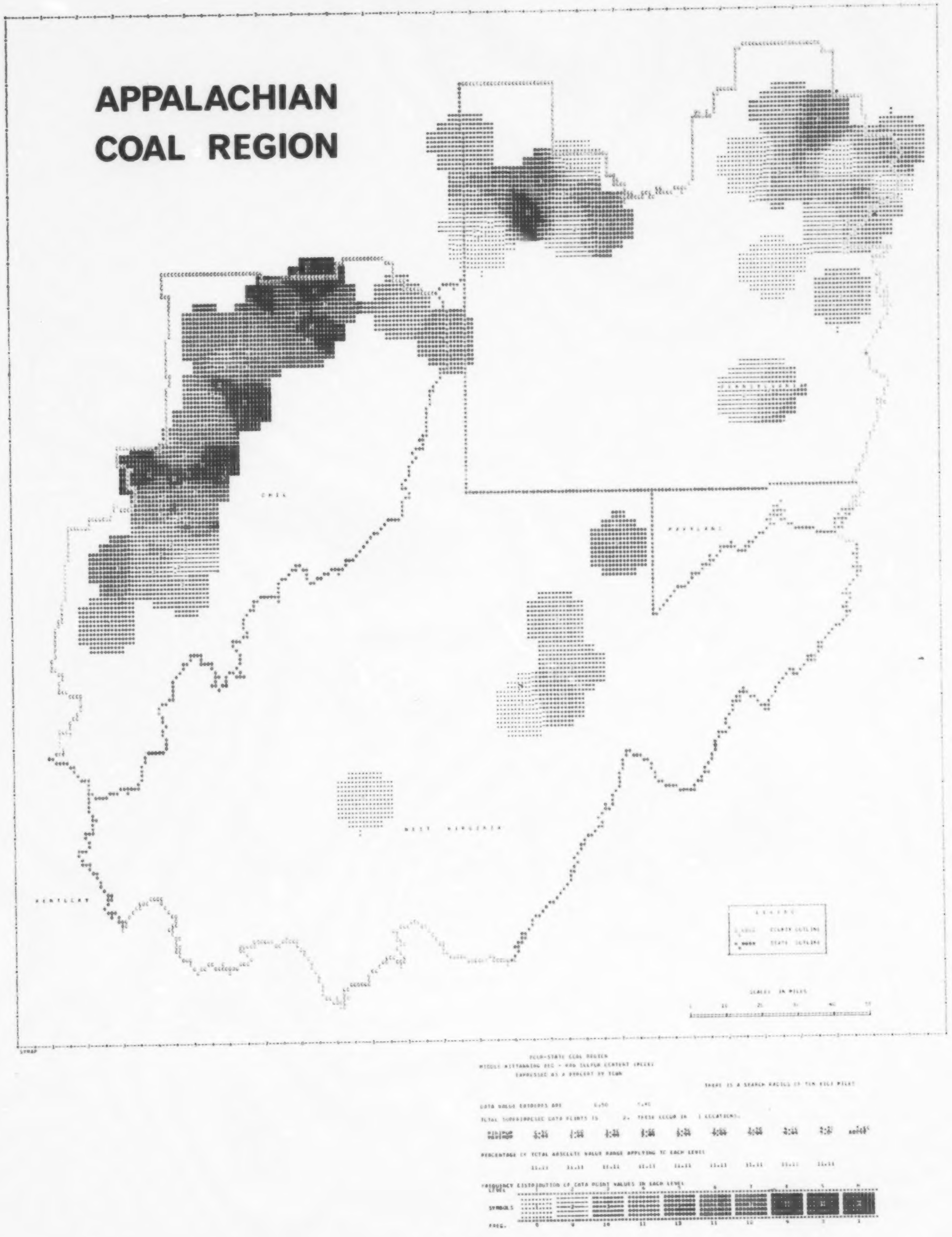

APPALACHIAN
COAL REGION
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
SCALE IN MILES

Figure C-6
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
10 Mile Search Radius

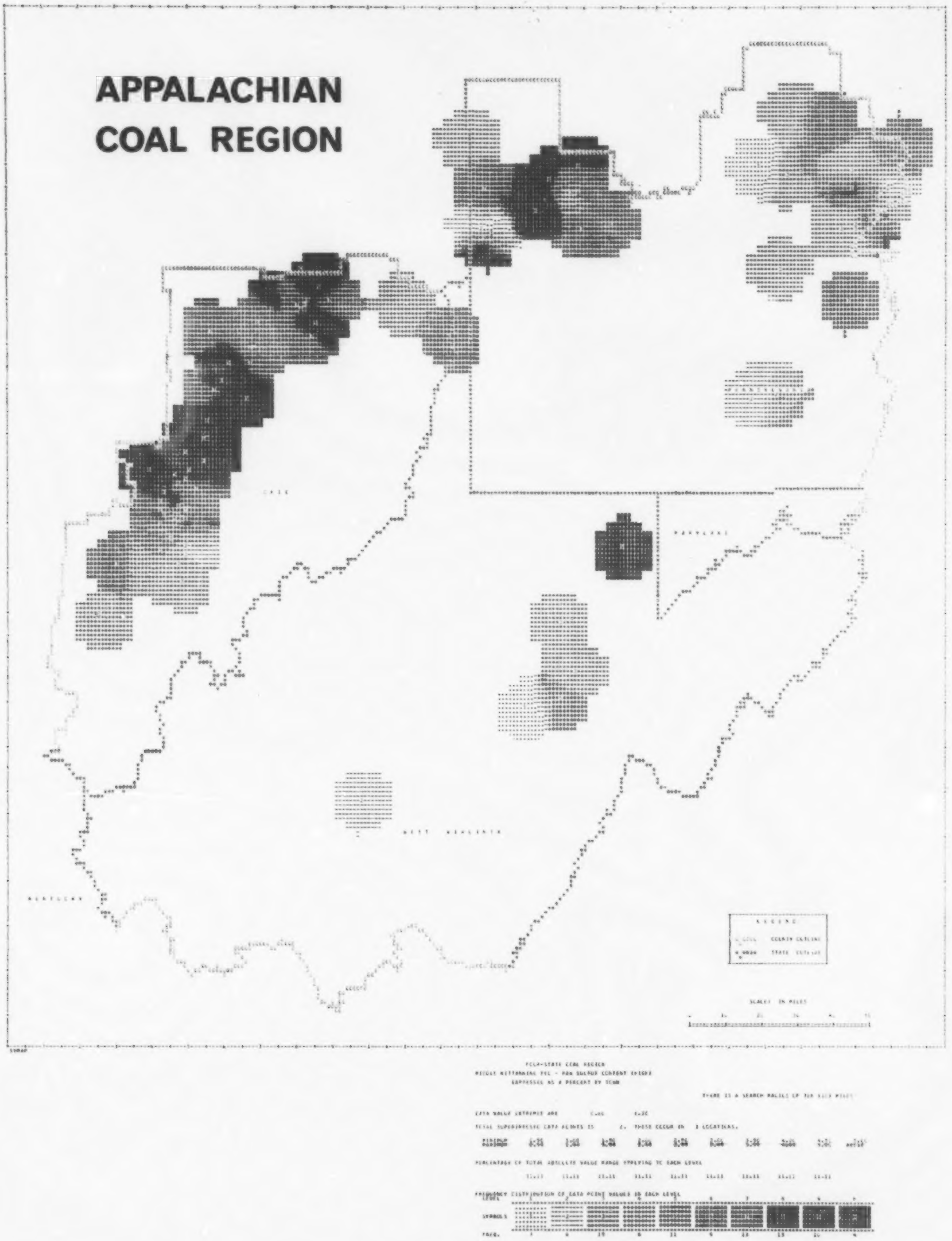

APPALACHIAN
COAL REGION

Figure C-7
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
10 Mile Search Radius

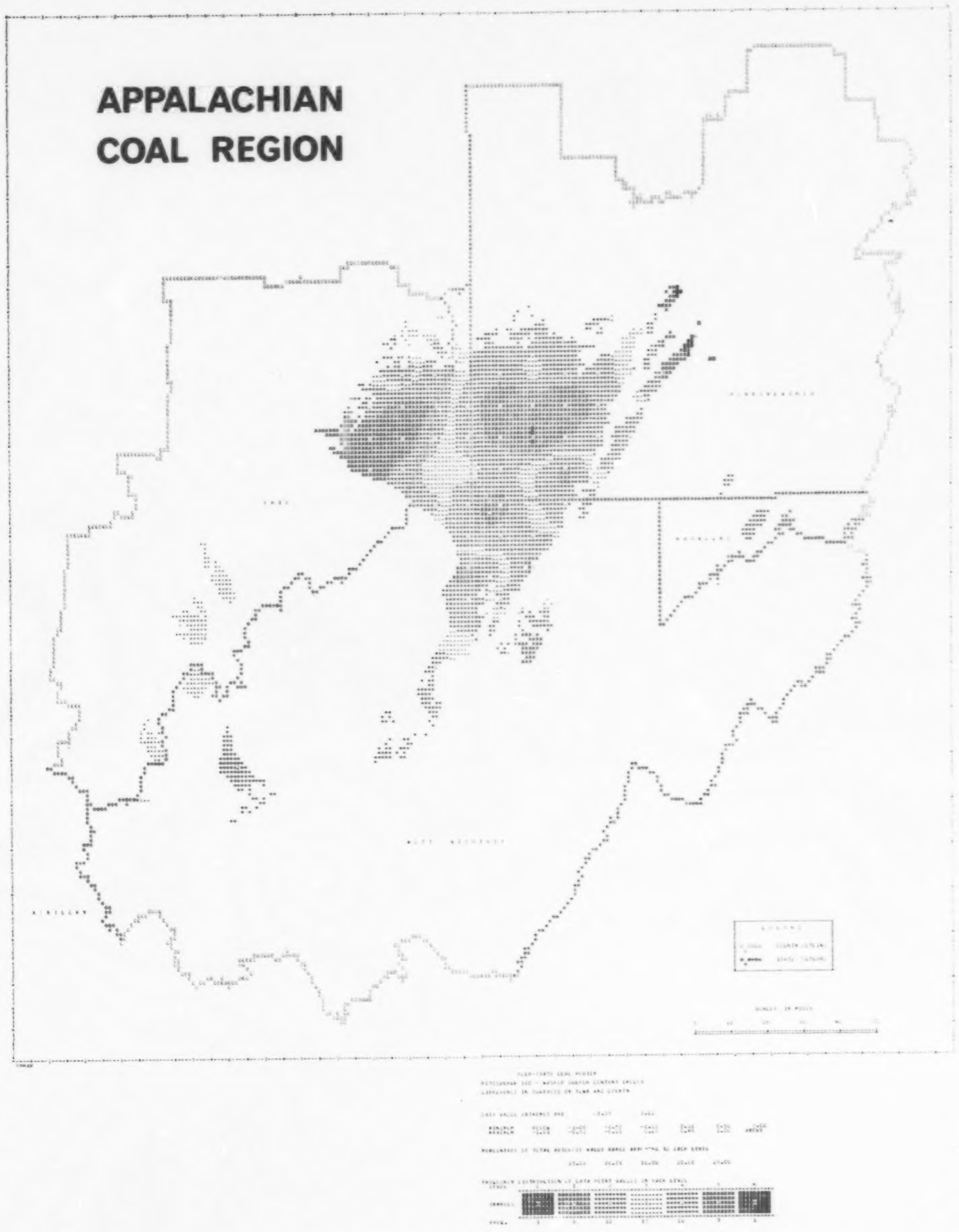

APPALACHIAN
COAL REGION

Figure D-1
Pittsburgh Coal Bed
Sulfur Content - Surface Comparison
Mode Values for Washed Samples
Mapped by Counties versus Mapped by Towns

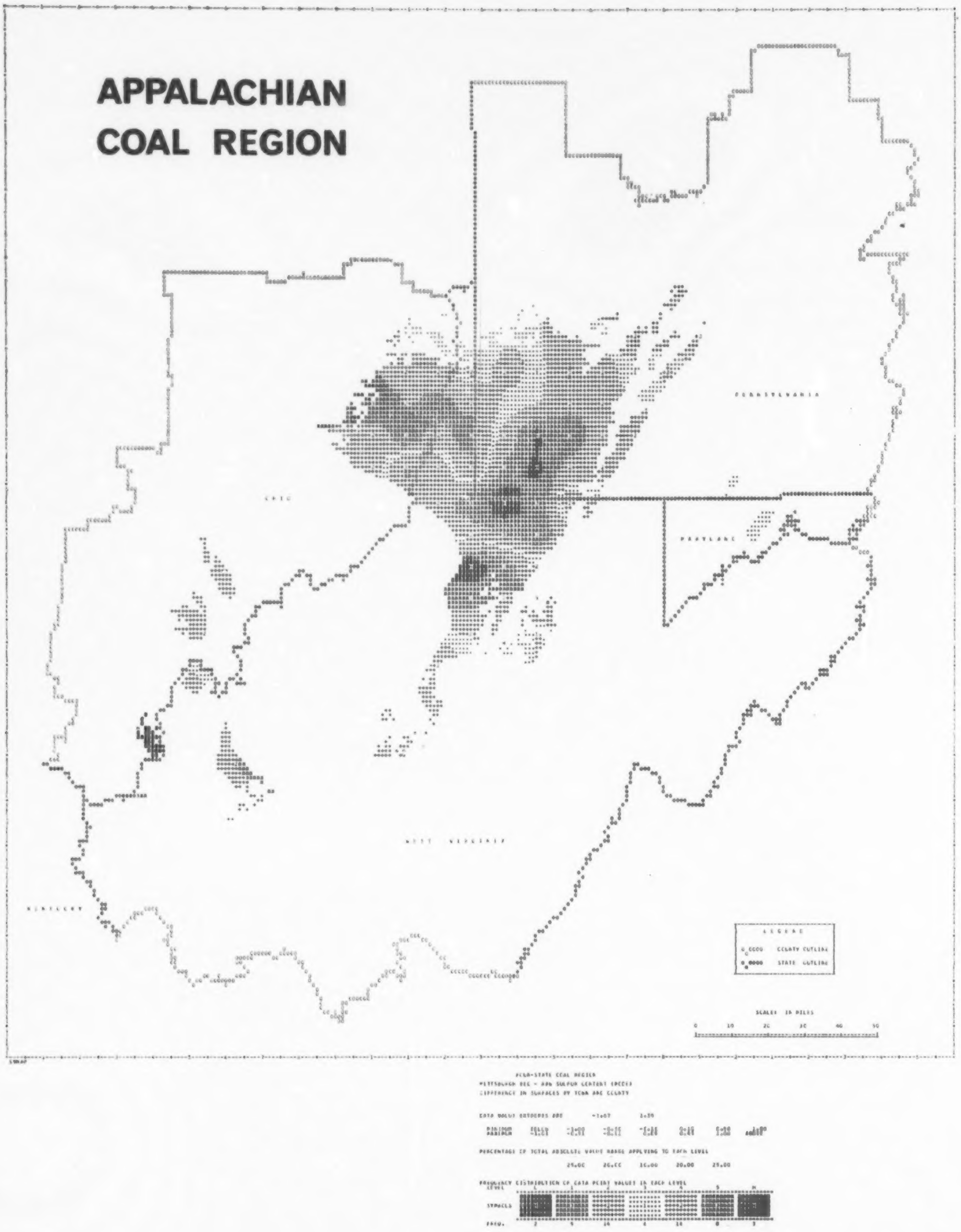
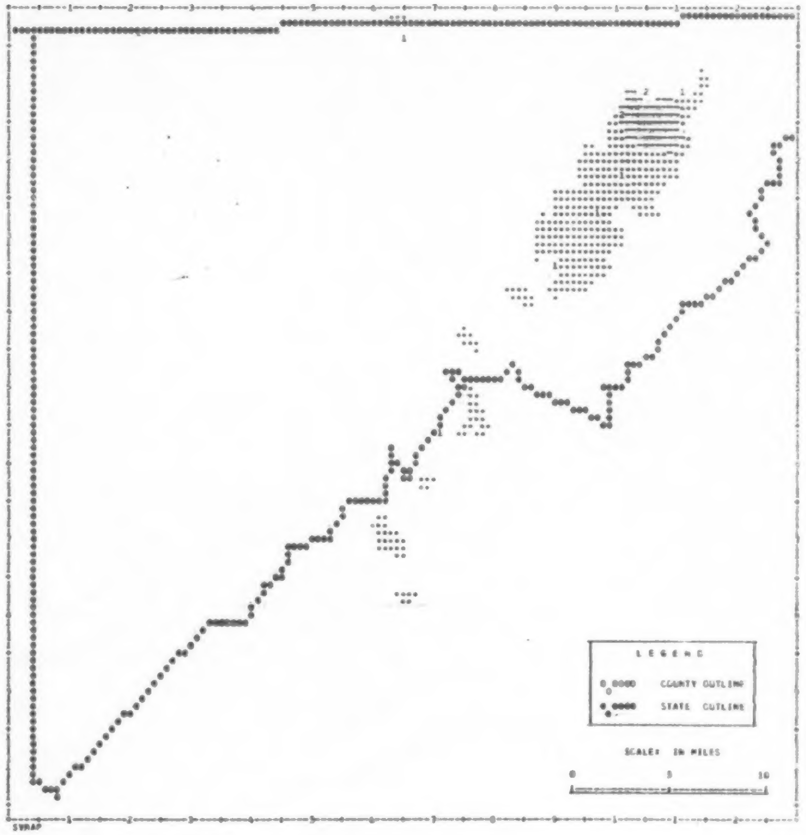

APPALACHIAN
COAL REGION
OHIO
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0 10 20 30 40 50
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
DIFFERENCE IN SURFACES BY TOWN AND COUNTY
DATA VALUE EXTREMES ARE -1.07 1.39
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
25.00 20.00 10.00 20.00 25.00
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL L 1 2 3 4 5 H
SYMBOLS
FREQ. 2 9 14 4 14 8 3

Figure D-2
Pittsburgh Coal Bed
Sulfur Content - Surface Comparison
Mode Values for Raw Samples
Mapped by Counties versus Mapped by Towns


LEGEND
0.0000 COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
SYMAP

```
GARRETT AND ALLEGANY COUNTIES, MARYLAND
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
     EXPRESSED AS A PERCENT BY TOWN

DATA VALUE EXTREMES ARE        0.60       5.30

 MINIMUM     0.50    1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50     5.00
 MAXIMUM     0.99    1.49    1.99    2.49    2.99    3.49    3.99    4.49    5.00    ABOVE

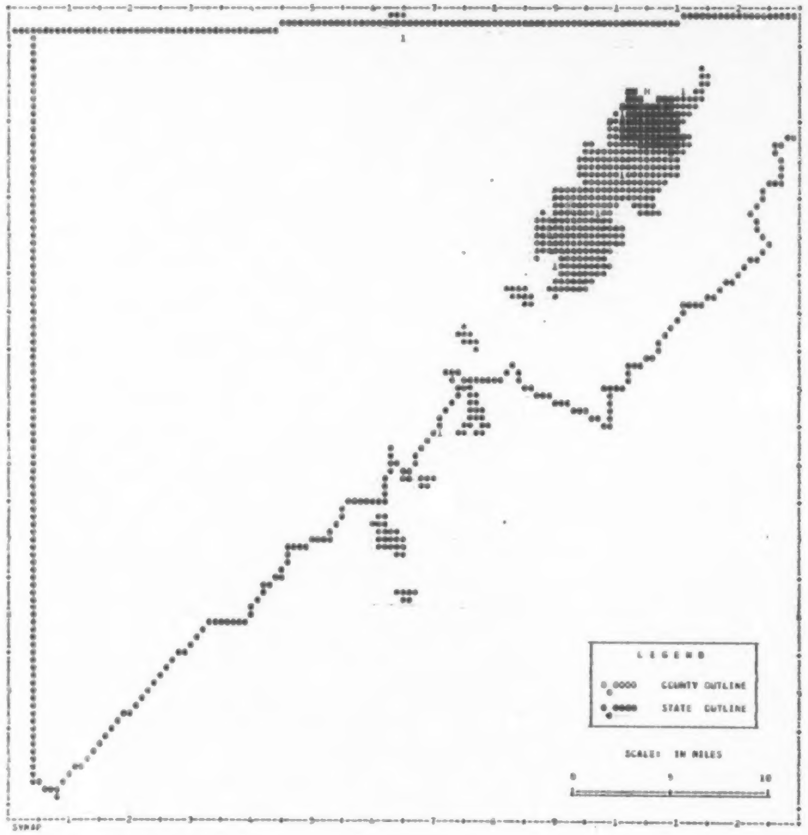
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1       2       3       4       5       6       7       8       9       H

 SYMBOLS

 FREQ.       26      38      23      24      19      24      24      15       8       2
```


LEGEND
0.0000 COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
SYMAP

```
GARRETT AND ALLEGANY COUNTIES, MARYLAND
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
     EXPRESSED AS A PERCENT BY TOWN

DATA VALUE EXTREMES ARE        0.60       5.30

 MINIMUM     0.50     1.00
 MAXIMUM     1.00    ABOVE

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1        H

 SYMBOLS

 FREQ.       38      165
```

Figure D-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Allegheny and Garrett Counties

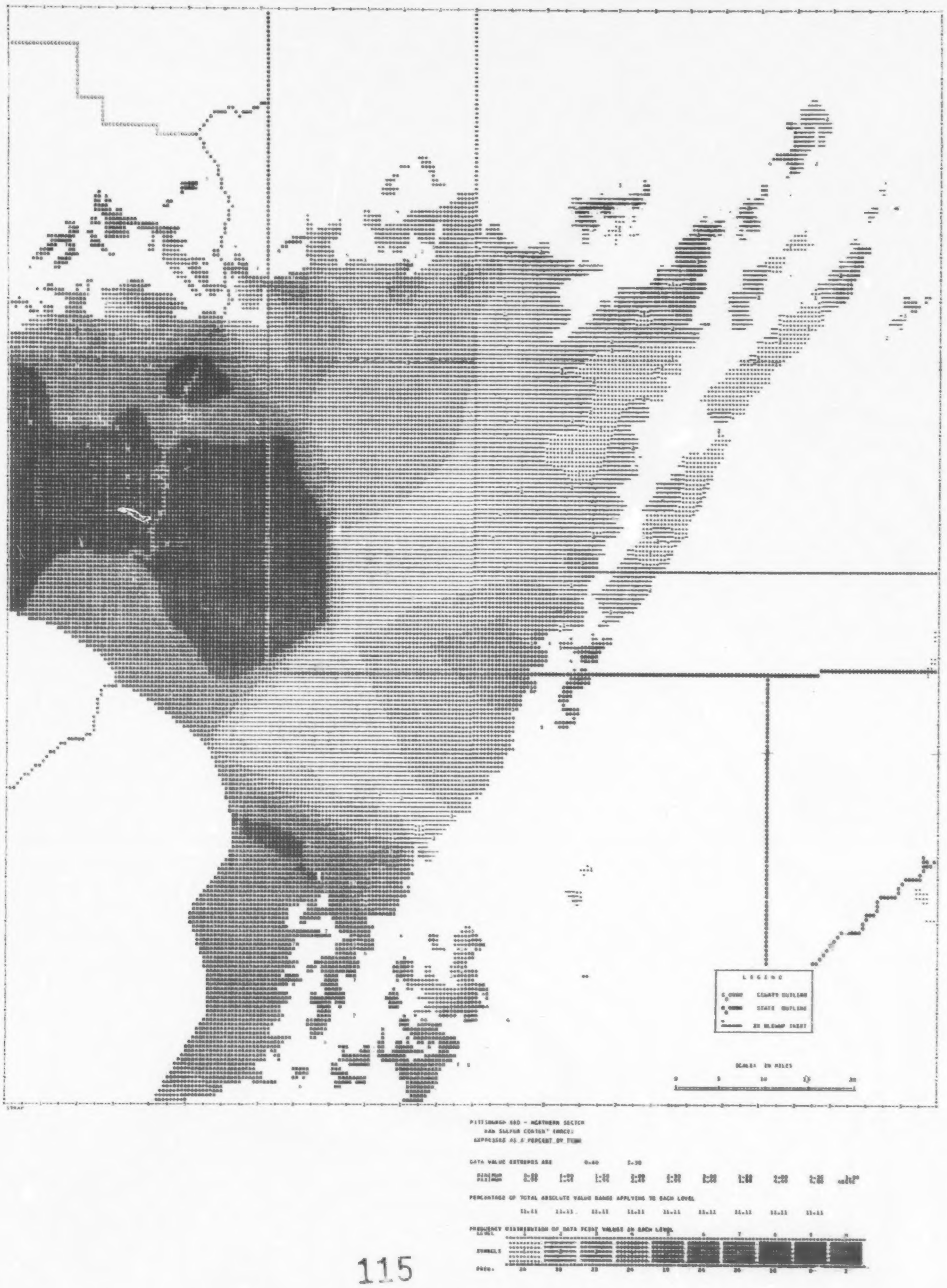

LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
15
20
PITTSBURGH BED - NORTHERN SECTOR
RAW SULFUR CONTENT INDEX:
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE 0.40 5.30
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure D-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Northern Sector

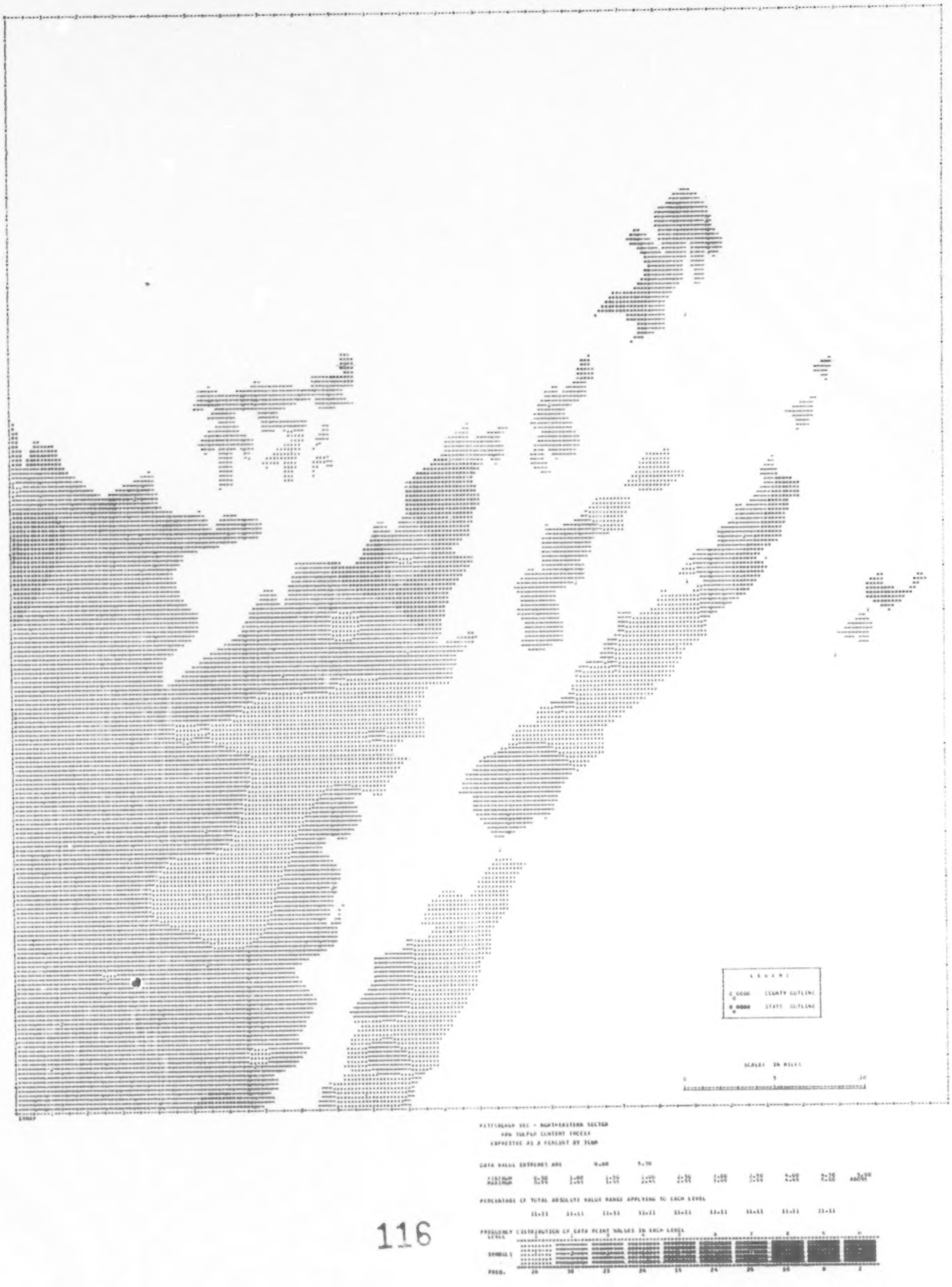

LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10
SYMAP
PITTSBURGH SEC - NORTHEASTERN SECTOR
RAW SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE 0.00 5.50
MINIMUM
MAXIMUM
ABOVE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure D-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(Blow up of upper right quadrant of D-4)

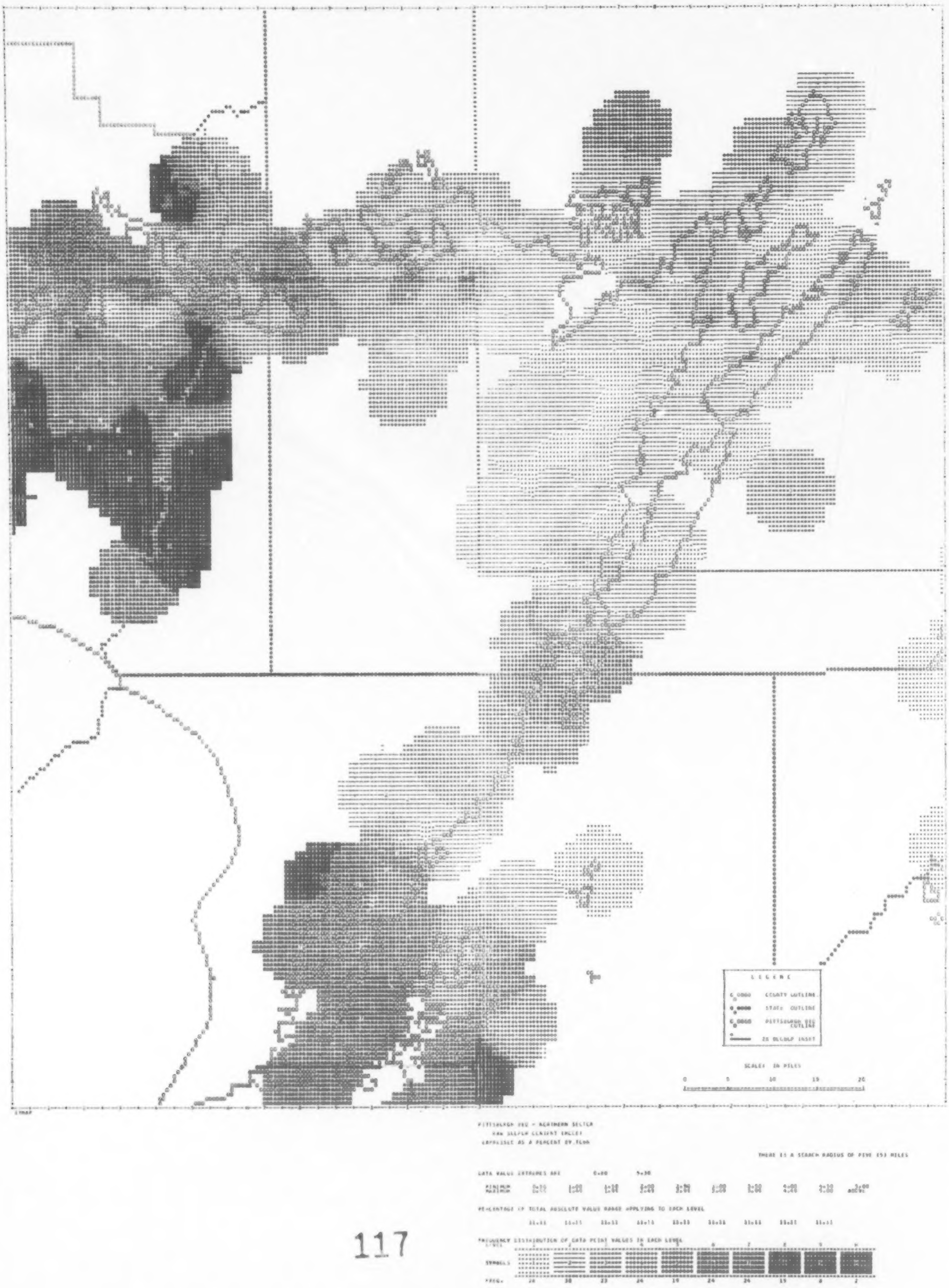

LEGEND
COUNTY OUTLINE
STATE OUTLINE
PITTSBURGH BED OUTLINE
SCALE: IN MILES
0
5
10
15
20
PITTSBURGH BED - NORTHERN SECTOR
RAW SULFUR CONTENT
EXPRESSED AS A PERCENT BY TOWN
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure D-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Northern Sector
5 Mile Search Radius

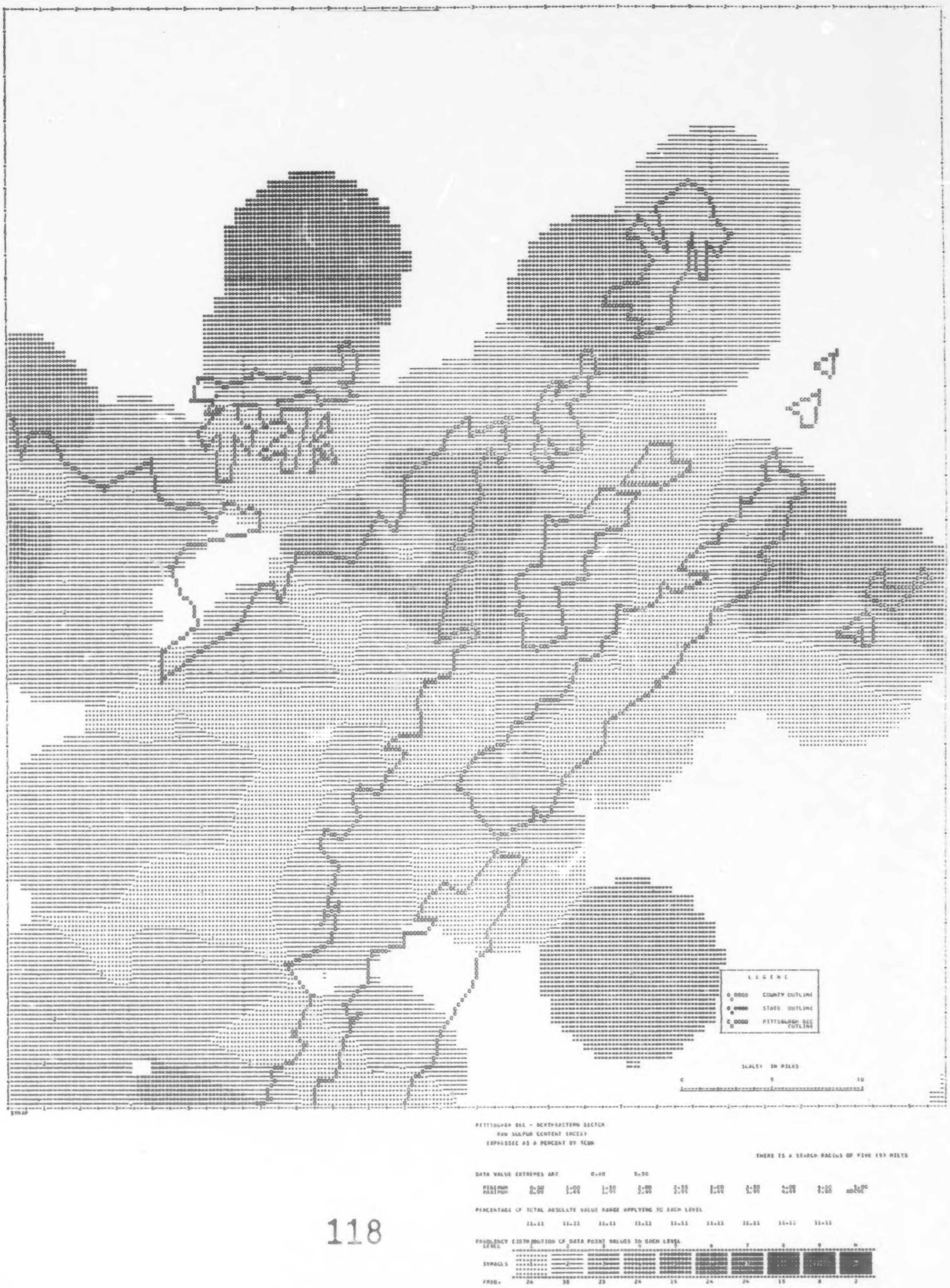
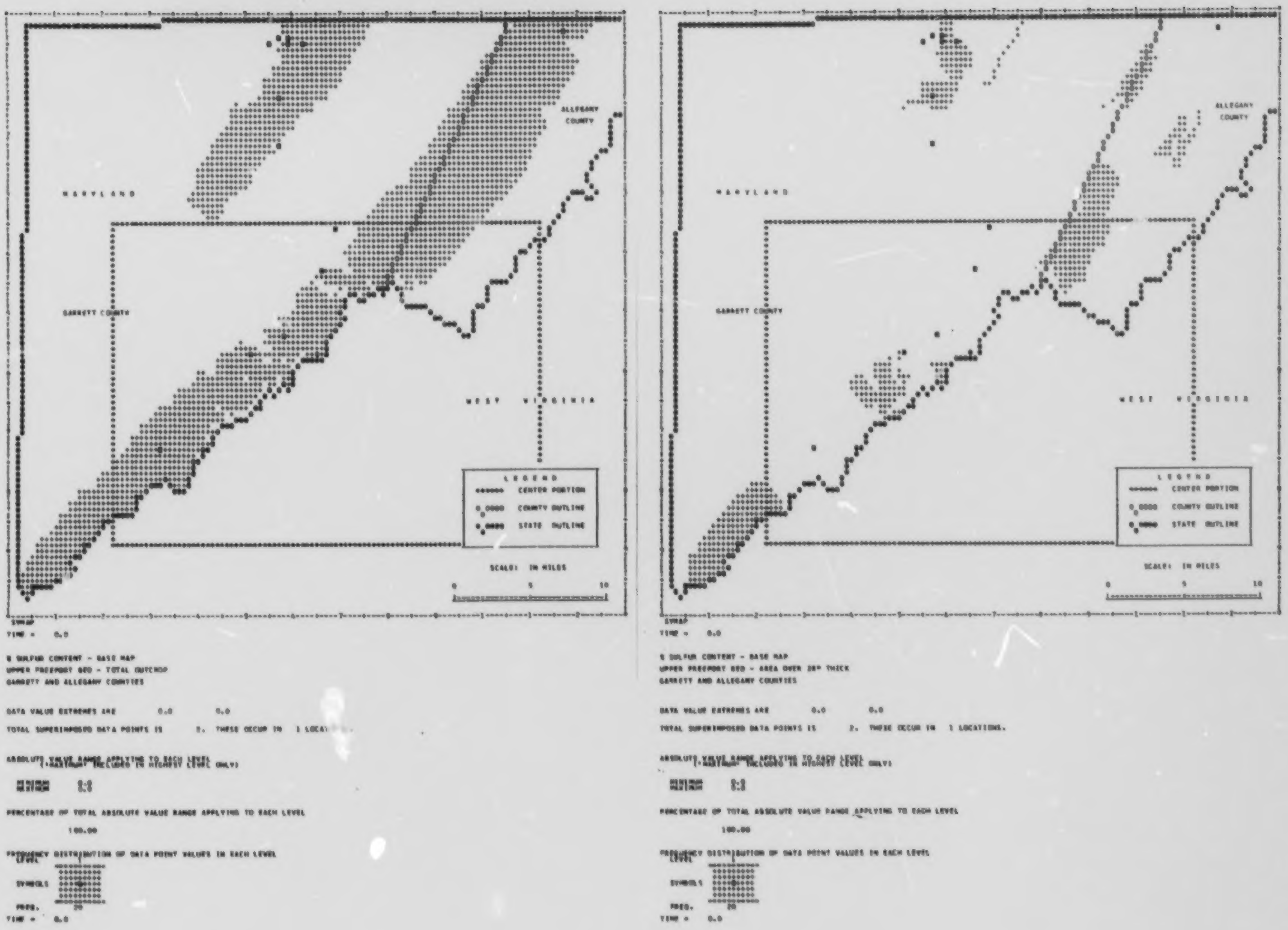

LEGEND
COUNTY OUTLINE
STATE OUTLINE
PITTSBURGH BED OUTLINE
SCALE: IN MILES
0
5
10
PITTSBURGH BED - NORTHEASTERN SECTOR
RAW SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TONS
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE 0.40 5.30
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ. 26 30 23 24 15 24 24 15 8 2

Figure D-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(Blow up of upper right quadrant of D-4)
5 Mile Search Radius


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
CENTER PORTION
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
SYMAP
SYMBOLS
LEVEL
FREQ.
20

```
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER FREEPORT BED - TOTAL OUTCROP
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0

TOTAL SUPERIMPOSED DATA POINTS IS       2.  THESE OCCUR IN   1 LOCA[illegible]

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM     0.0
  MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

TIME =    0.0
```

```
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER FREEPORT BED - AREA OVER 28" THICK
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0

TOTAL SUPERIMPOSED DATA POINTS IS       2.  THESE OCCUR IN   1 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM     0.0
  MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

TIME =    0.0
```

Figure E-1
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Base Map for Raw Samples
left: total outcrop; right: area over 28" thick

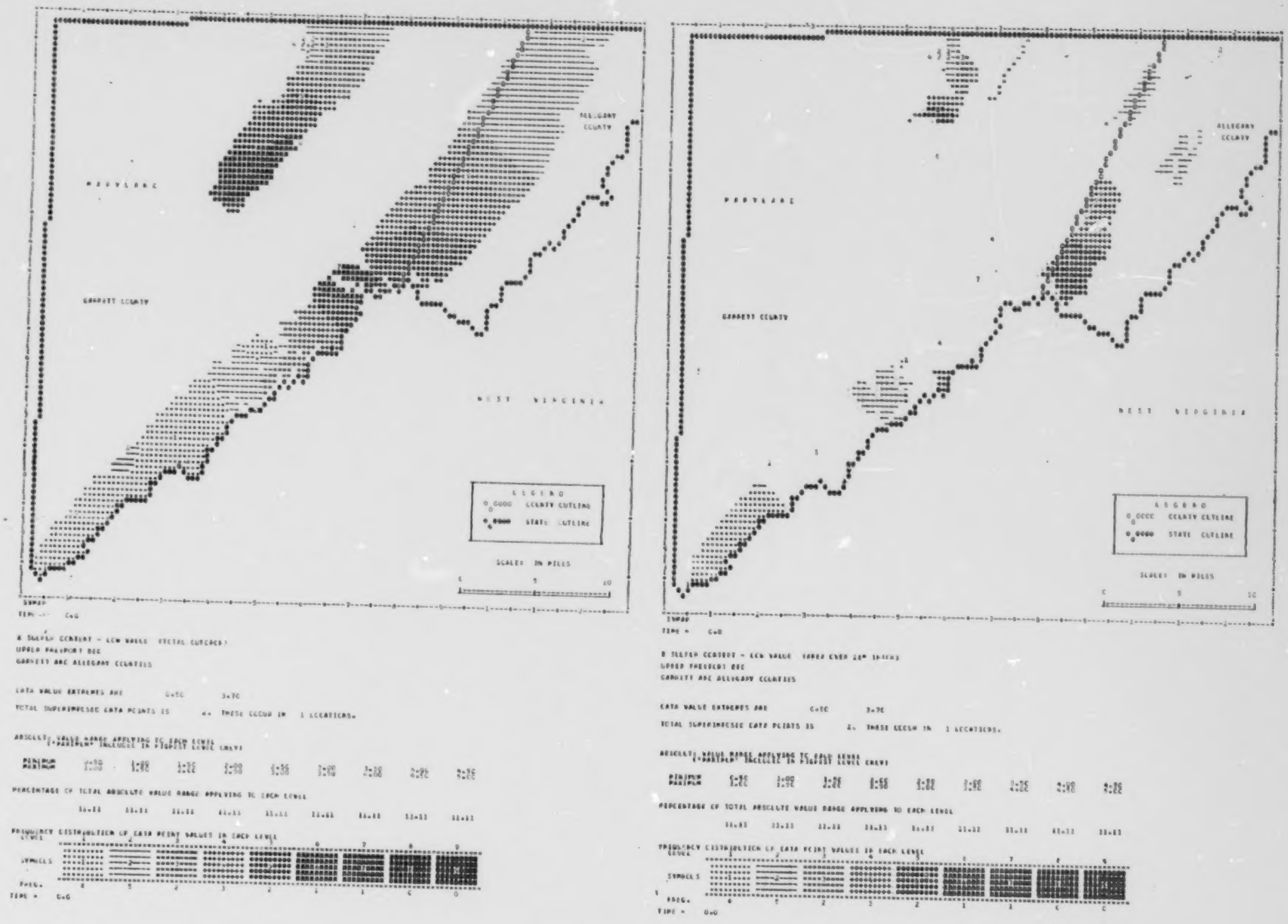

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10

Figure E-2
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick

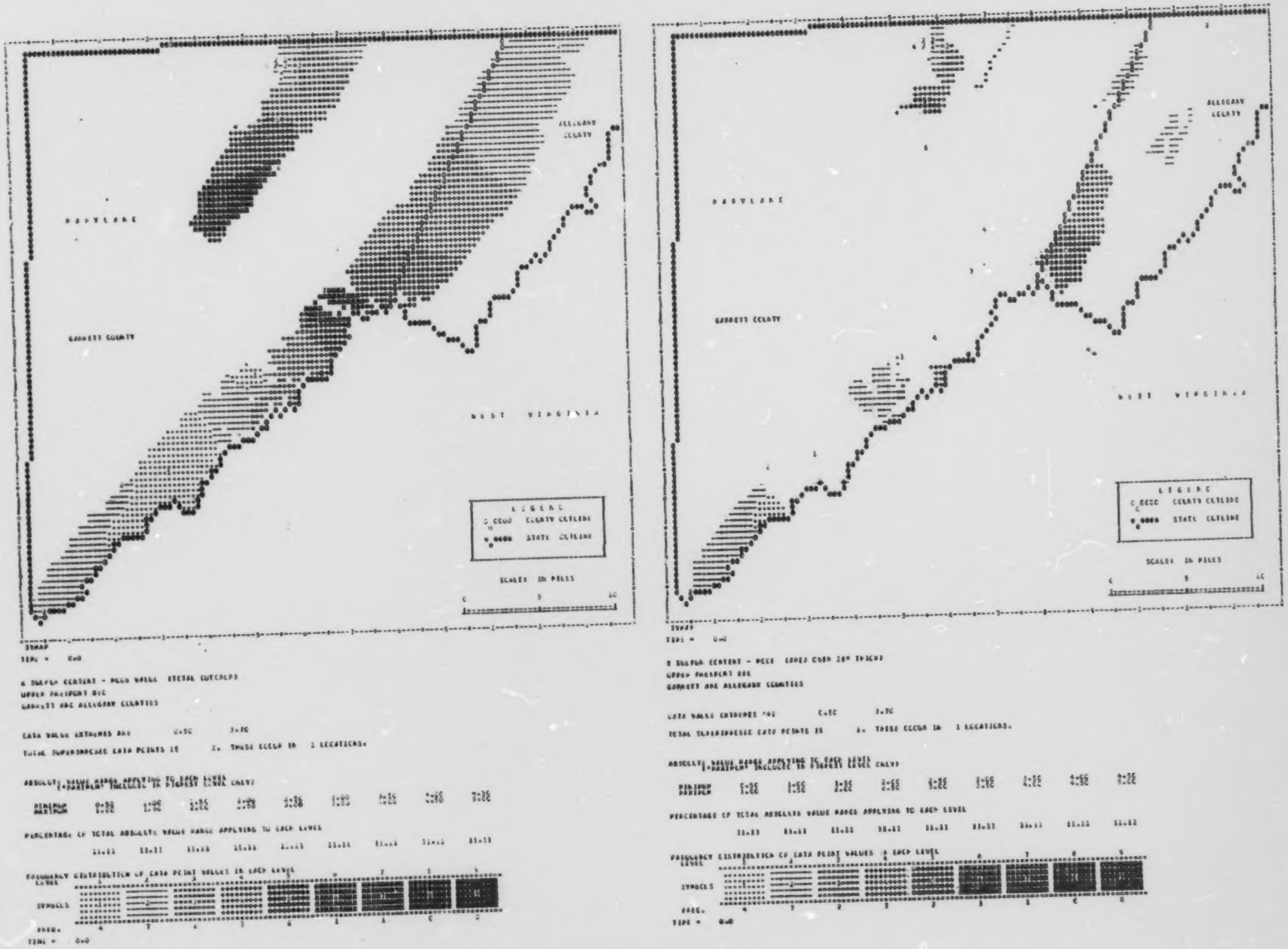


Figure E-3
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

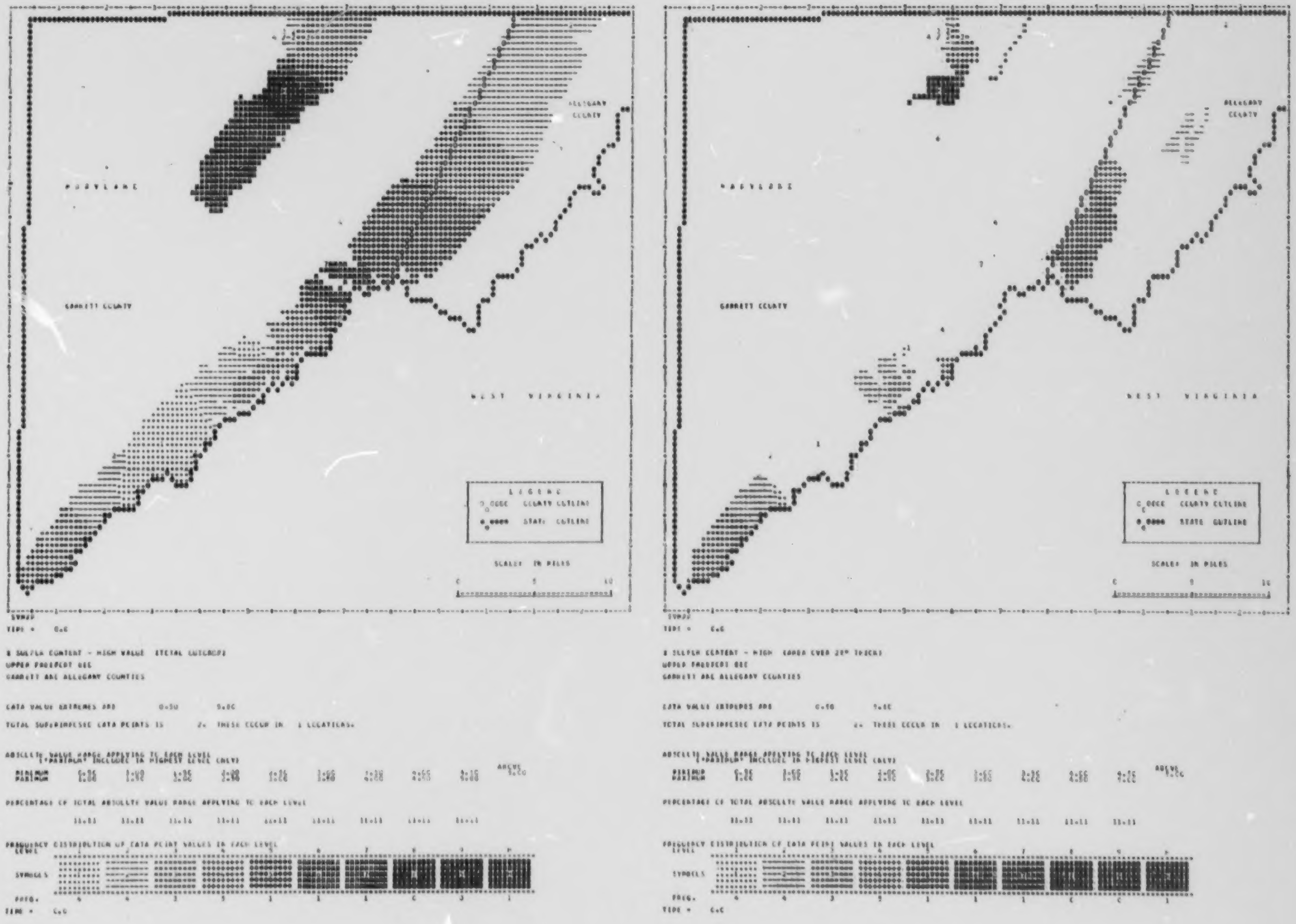
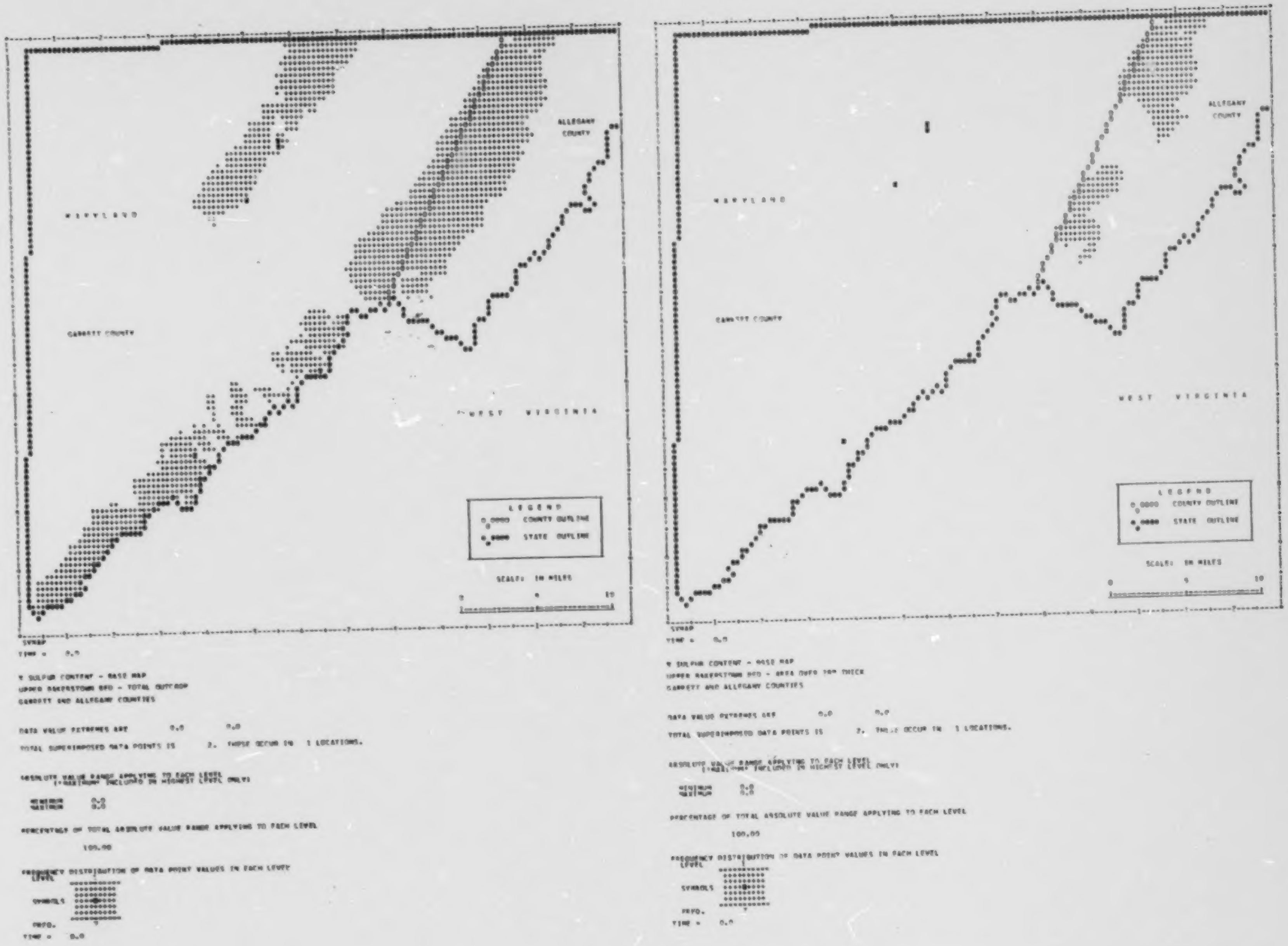

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10
MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10

Figure E-4
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick



```
SYMAP
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER BAKERSTOWN BED - TOTAL OUTCROP
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0
TOTAL SUPERIMPOSED DATA POINTS IS      2.  THESE OCCUR IN   1 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
     (*MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.0
 MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

          100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL         1

 SYMBOLS

 FREQ.         [illegible]
TIME =    0.0
```

```
SYMAP
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER BAKERSTOWN BED - AREA OVER 28" THICK
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0
TOTAL SUPERIMPOSED DATA POINTS IS      2.  THESE OCCUR IN   1 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
     (*MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.0
 MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

          100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL         1

 SYMBOLS

 FREQ.         [illegible]
TIME =    0.0
```

Figure E-5
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Base Map for Raw Samples
left: total outcrop; right: area over 28" thick

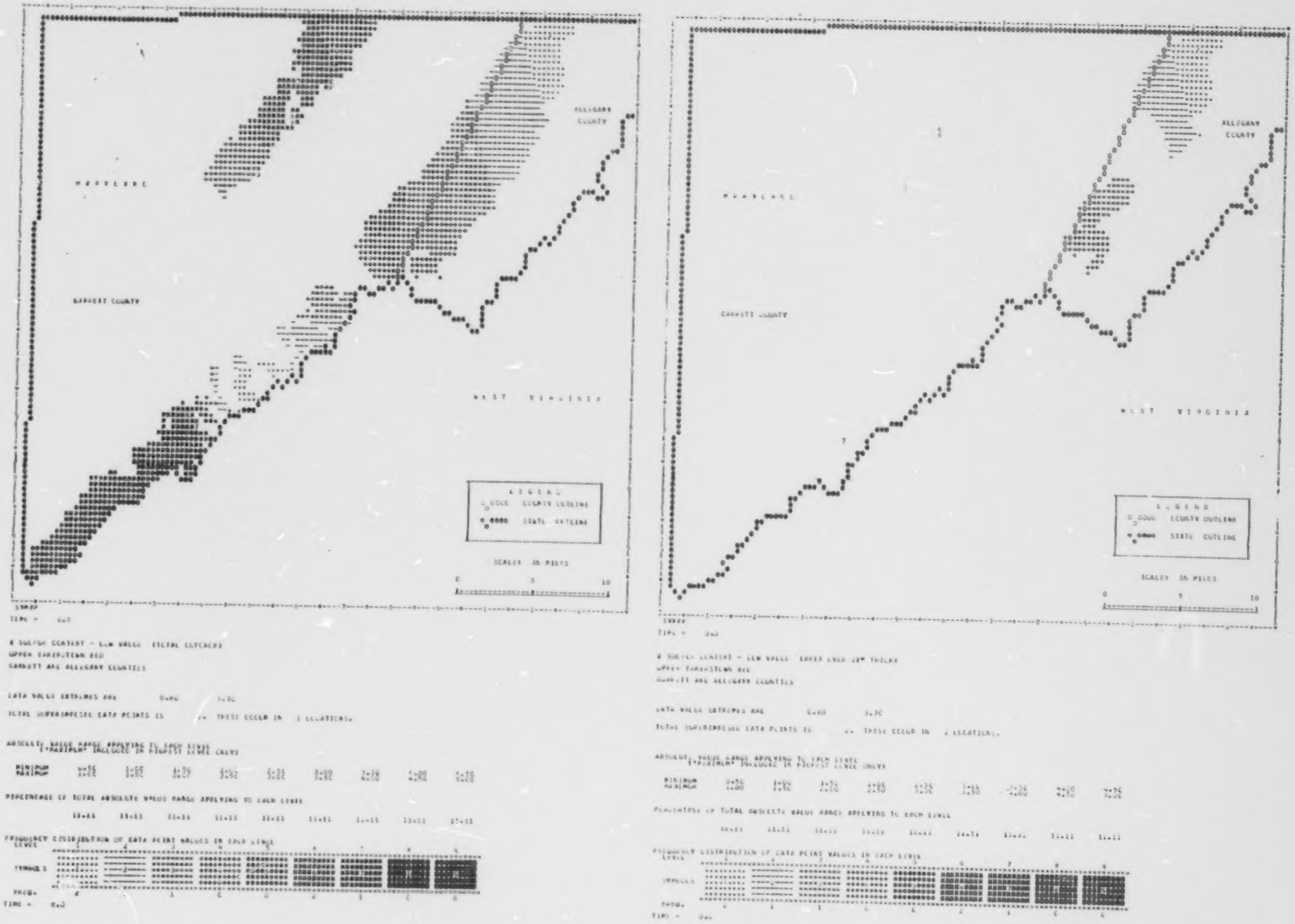

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10
SYMAP
MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
0
5
10
SYMAP

Figure E-6
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick

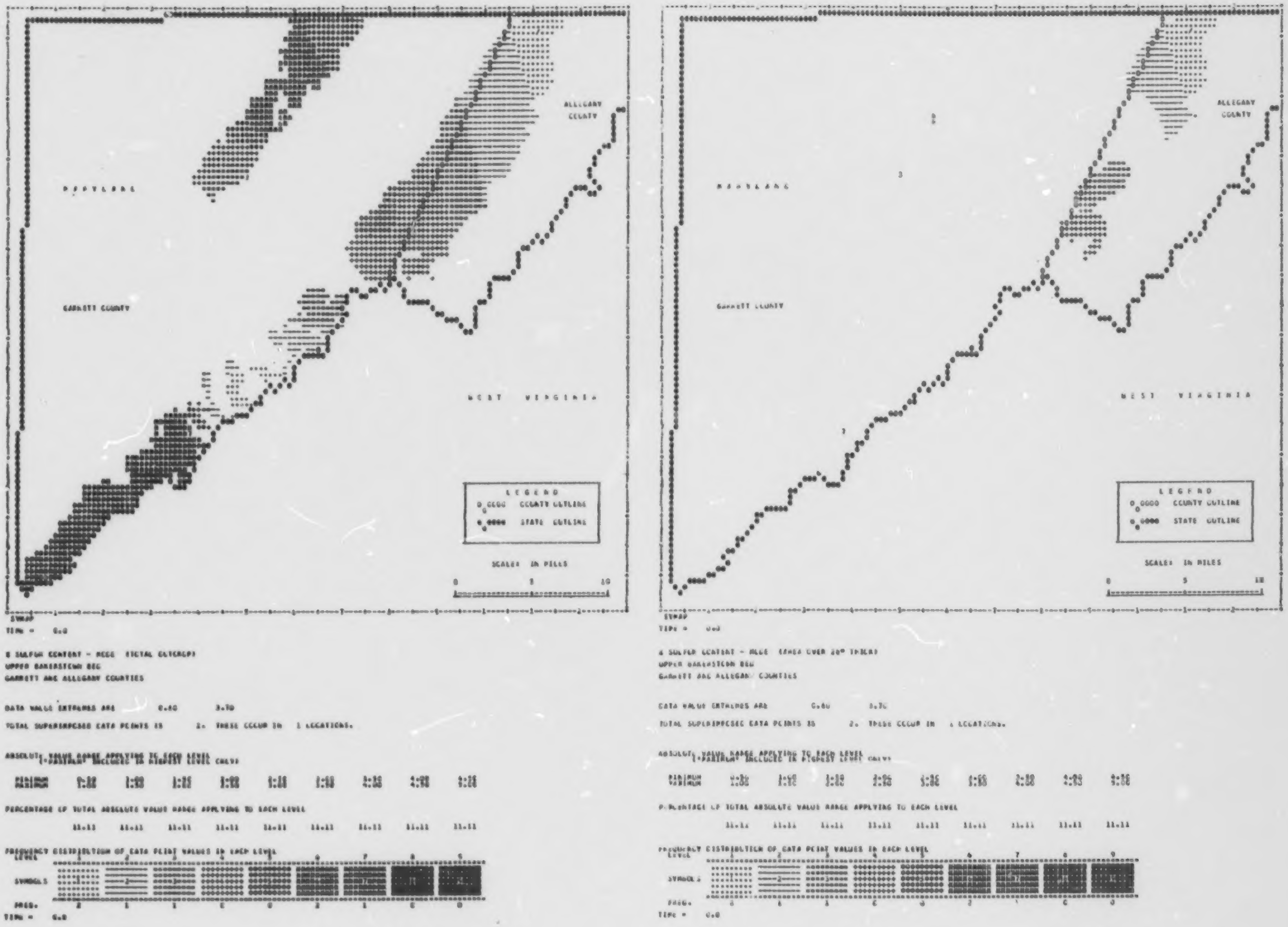

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10

Figure E-7
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

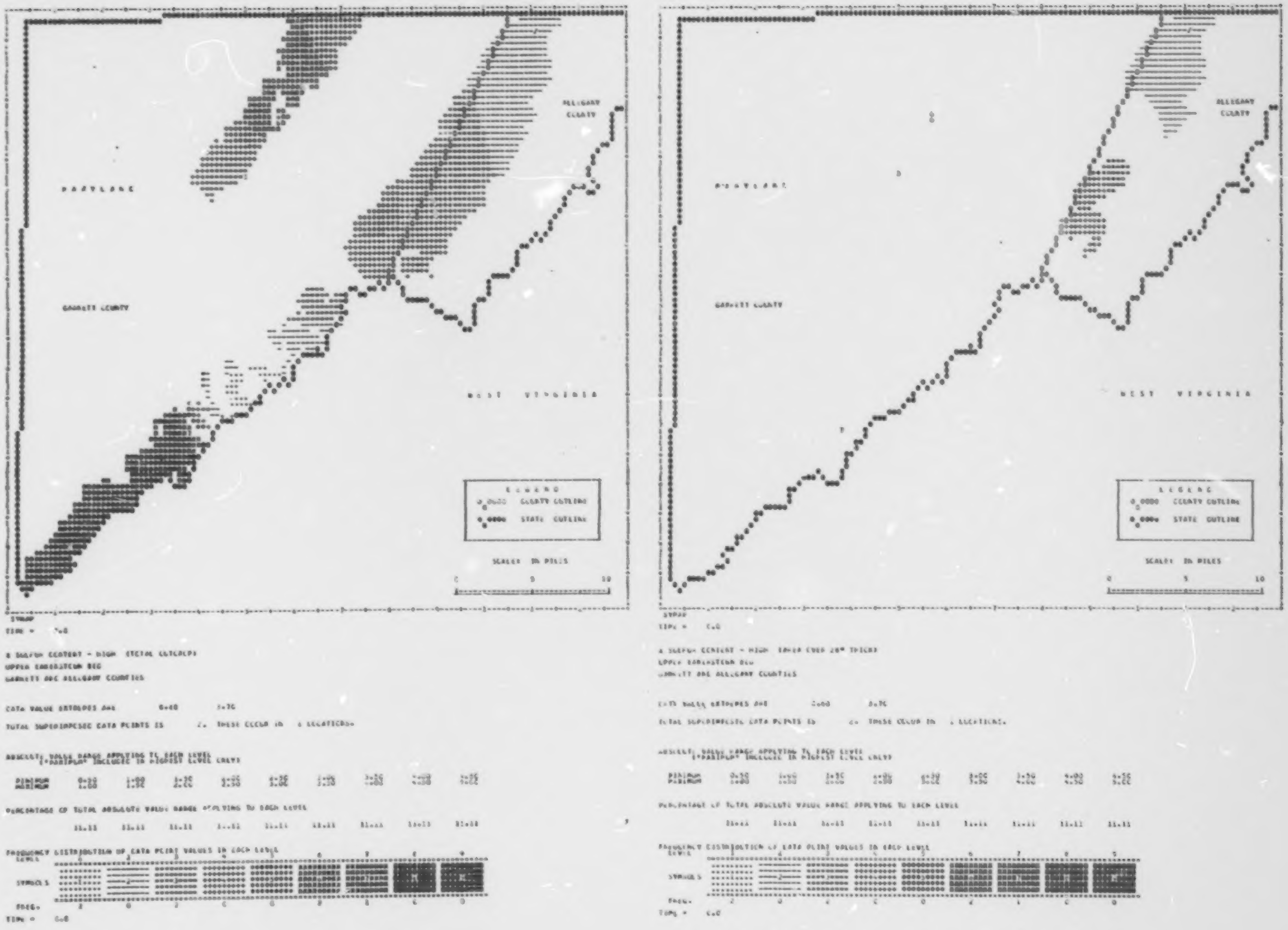
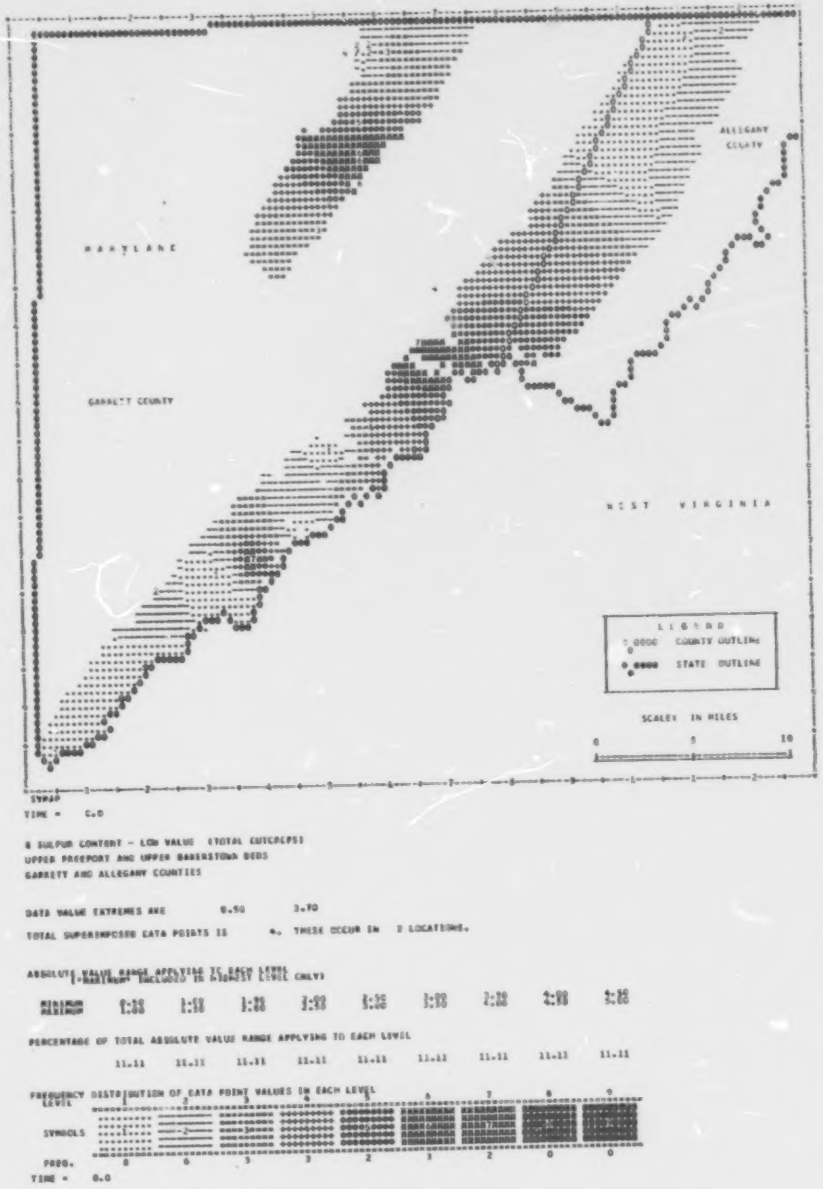

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10

Figure E-8
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10

```
SYMAP
TIME =    0.0

% SULFUR CONTENT - LOW VALUE  (TOTAL OUTCROPS)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE         0.50        3.70

TOTAL SUPERIMPOSED DATA POINTS IS       4.  THESE OCCUR IN   2 LOCATIONS.

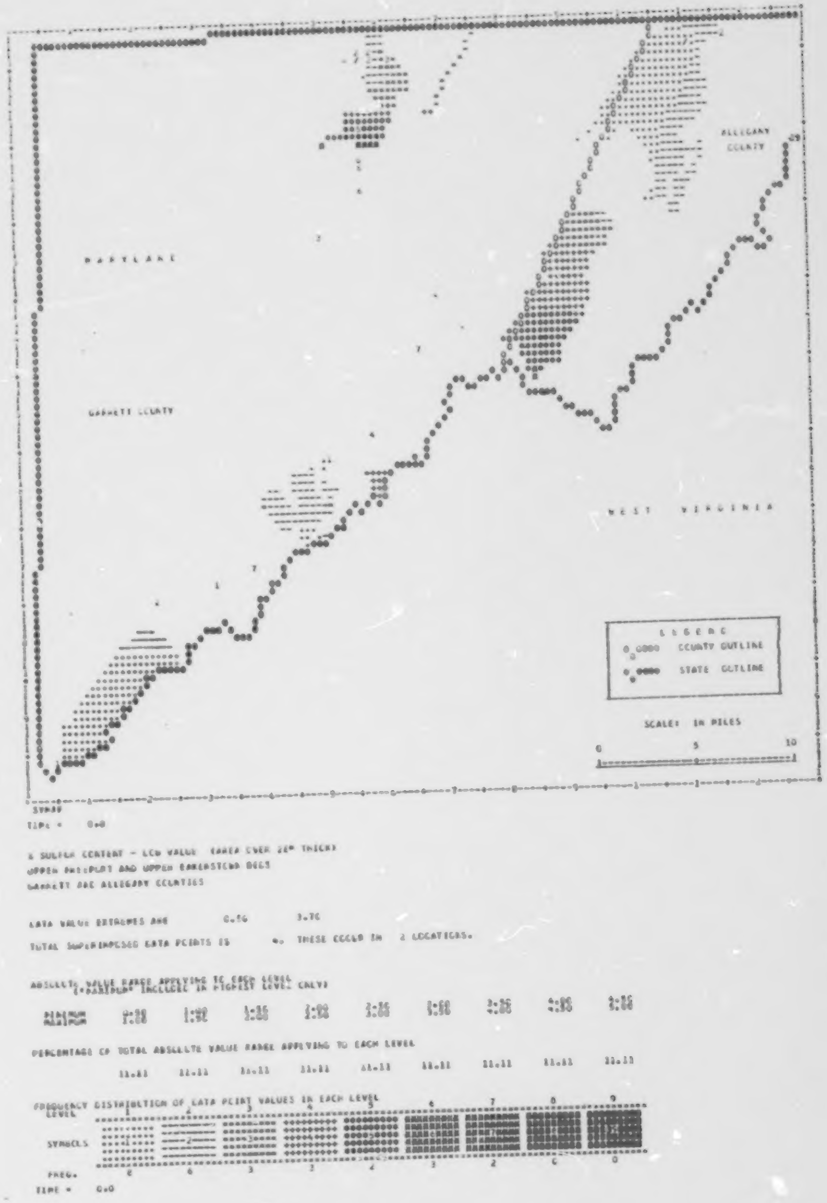
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
     ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM
  MAXIMUM

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1       2       3       4       5       6       7       8       9
  SYMBOLS
  FREQ.        8       6       3       3       2       3       2       0       0
TIME =    0.0
```


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10

```
SYMAP
TIME =    0.0

% SULFUR CONTENT - LOW VALUE  (AREA OVER 28" THICK)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE         0.56        3.76

TOTAL SUPERIMPOSED DATA POINTS IS       4.  THESE OCCUR IN   2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
     ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

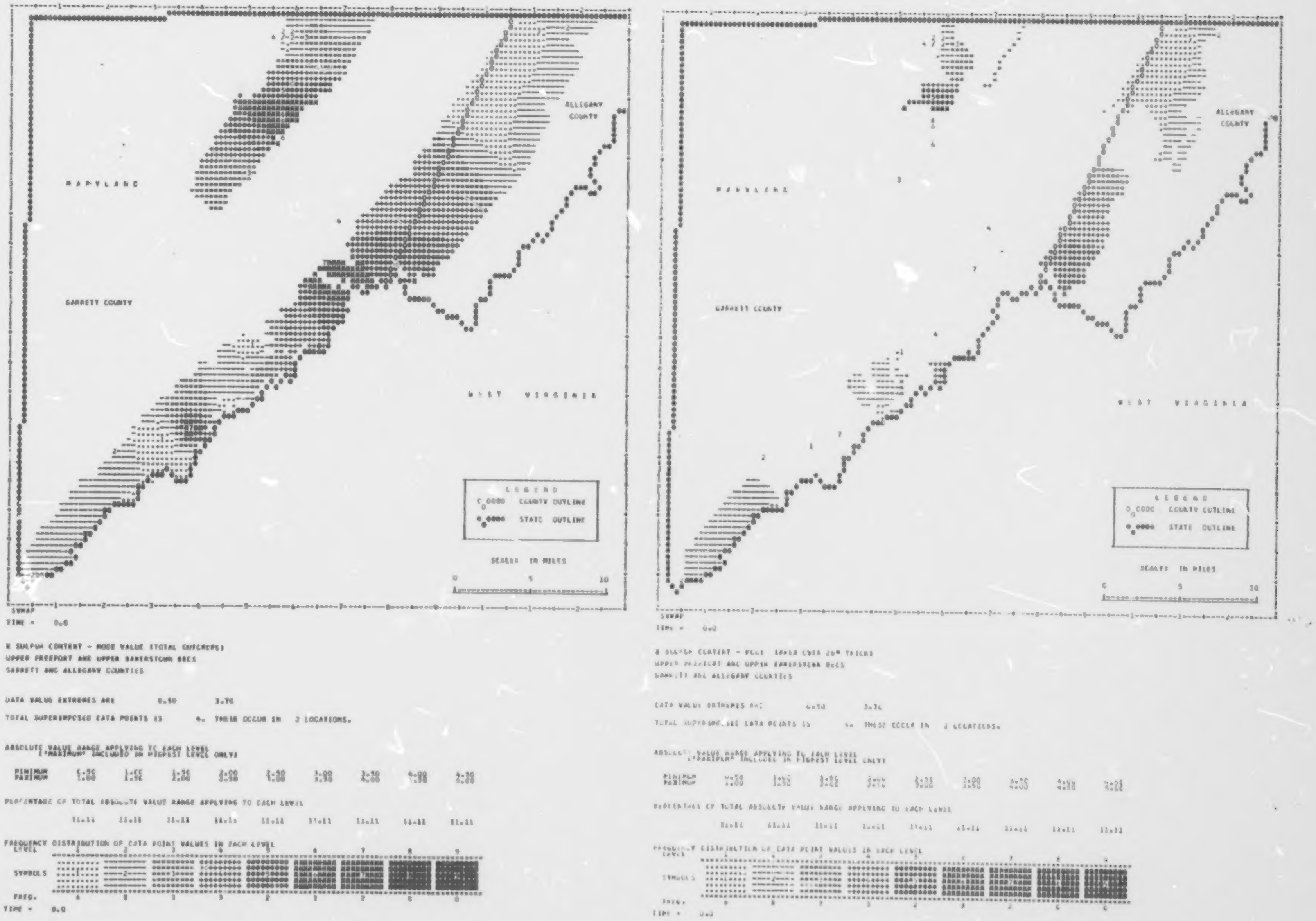
  MINIMUM
  MAXIMUM

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1       2       3       4       5       6       7       8       9
  SYMBOLS
  FREQ.        8       6       3       3       4       3       2       0       0
TIME =    0.0
```

Figure E-9
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALES IN MILES
0
5
10
SYMAP
LEVEL
SYMBOLS
FREQ.

```
SYMAP
TIME =    0.0

% SULFUR CONTENT - MODE VALUE (TOTAL OUTCROPS)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE          0.50        3.70

TOTAL SUPERIMPOSED DATA POINTS IS       4.  THESE OCCUR IN   2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.50    1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50
 MAXIMUM     1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50    5.00

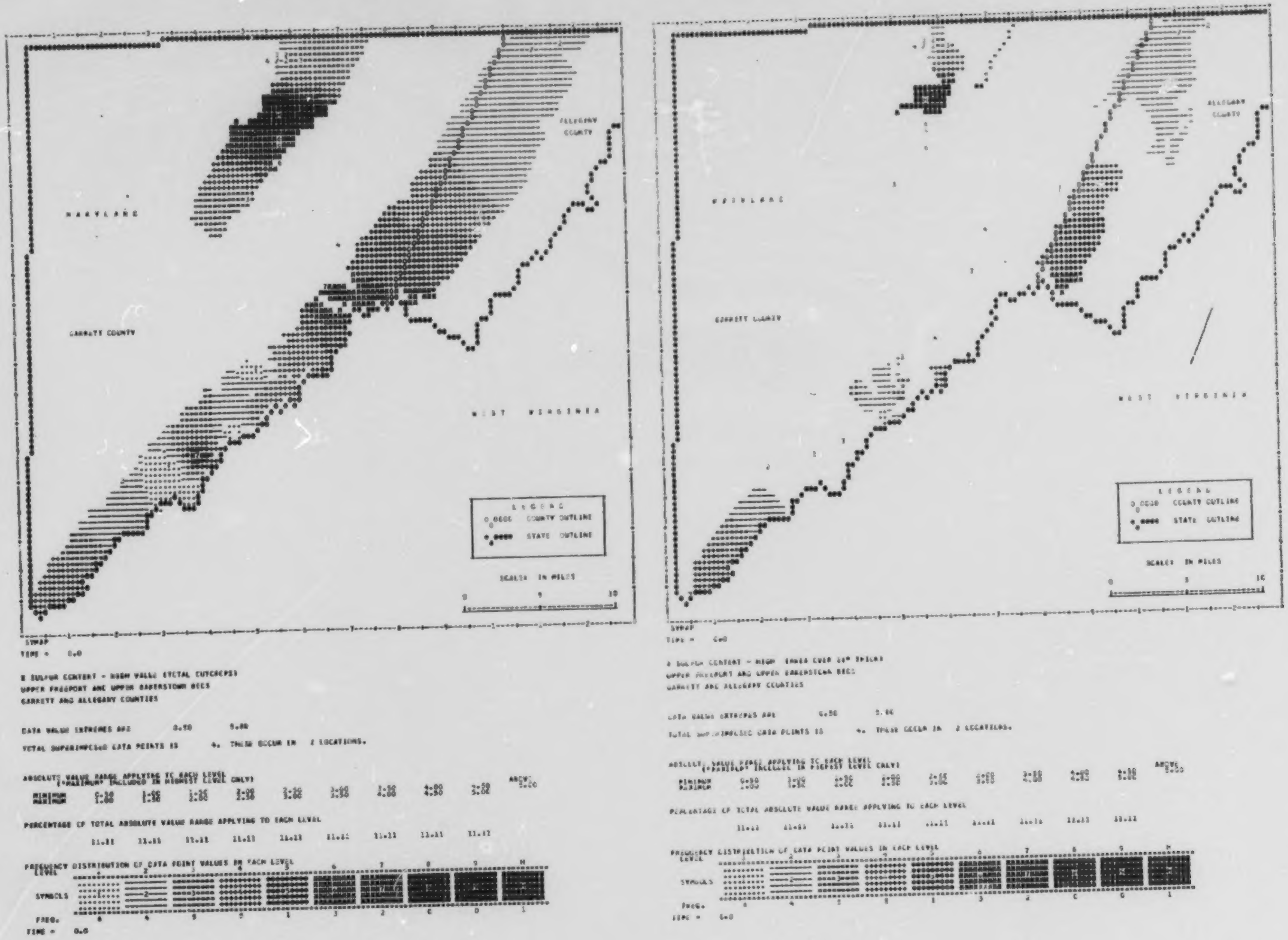
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1       2       3       4       5       6       7       8       9

 FREQ.        6       8       3       3       2       3       2       0       0
TIME =    0.0
```

Figure E-10
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick



```
SYMAP
TIME =    0.0

% SULFUR CONTENT - HIGH VALUE (TOTAL OUTCROPS)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.50       5.80

TOTAL SUPERIMPOSED DATA POINTS IS      4.   THESE OCCUR IN   2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
    ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)
  MINIMUM     0.50    1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50    ABOVE
  MAXIMUM     1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50    5.00     5.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL       1       2       3       4       5       6       7       8       9       H

  SYMBOLS

  FREQ.       6       4       5       5       1       3       2       0       0       1
TIME =    0.0
```

```
SYMAP
TIME =    0.0

% SULFUR CONTENT - HIGH (AREA OVER 28" THICK)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.50       [illegible]

TOTAL SUPERIMPOSED DATA POINTS IS      4.   THESE OCCUR IN   2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
    ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)
  MINIMUM     0.50    1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50    ABOVE
  MAXIMUM     1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50    5.00     5.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL       1       2       3       4       5       6       7       8       9       H

  SYMBOLS

  FREQ.       [illegible]       4       5       8       1       3       2       0       0       1
TIME =    0.0
```

Figure E-11
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick

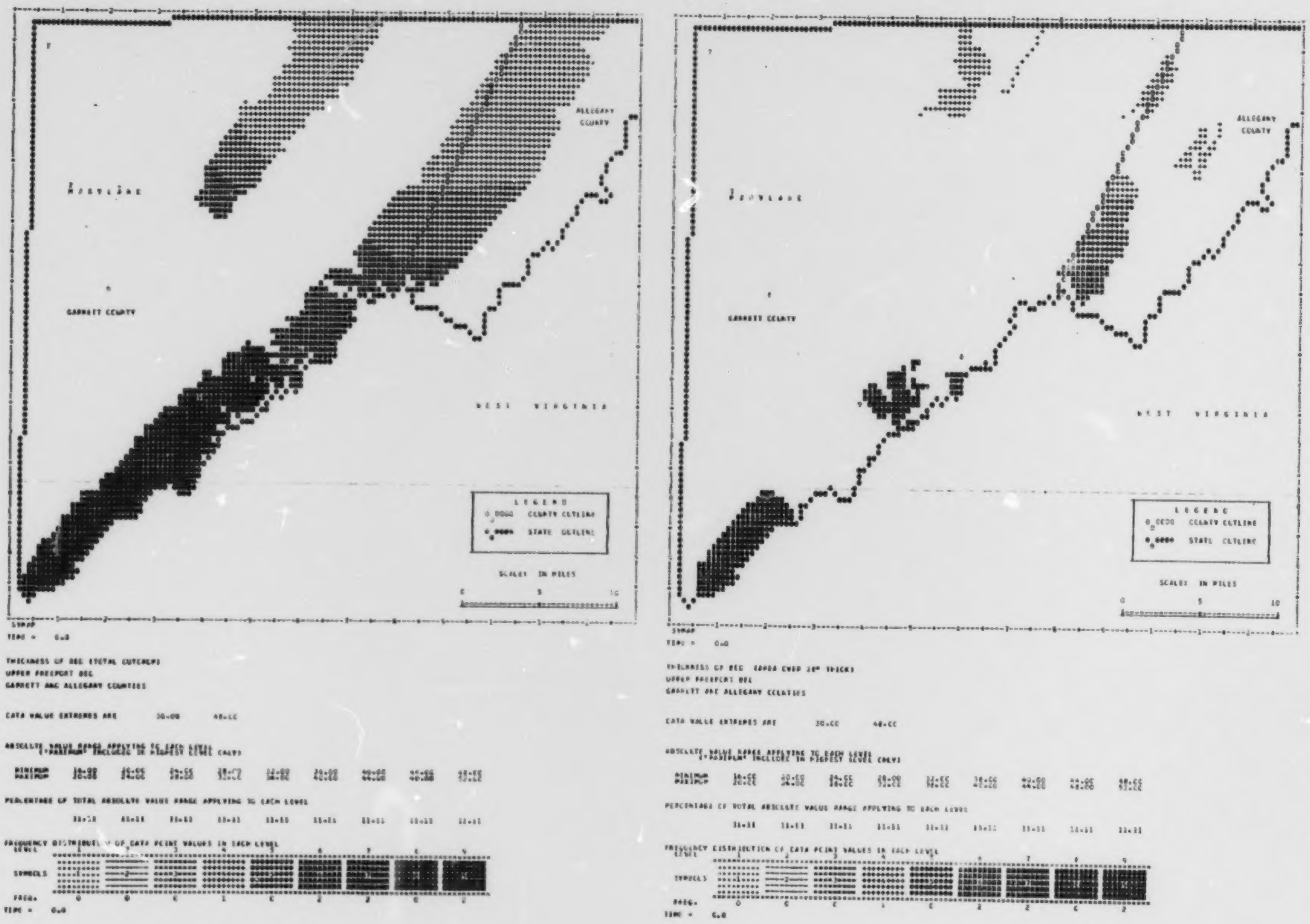

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
SYMAP
THICKNESS OF BED (TOTAL OUTCROP)
UPPER FREEPORT BED
GARRETT AND ALLEGANY COUNTIES
THICKNESS OF BED (AREA OVER 28" THICK)
UPPER FREEPORT BED
GARRETT AND ALLEGANY COUNTIES
DATA VALUE EXTREMES ARE
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure F-1
Allegany and Garrett Counties
Upper Freeport Coal Bed
Thickness of Bed
left: total outcrop; right: area over 28" thick

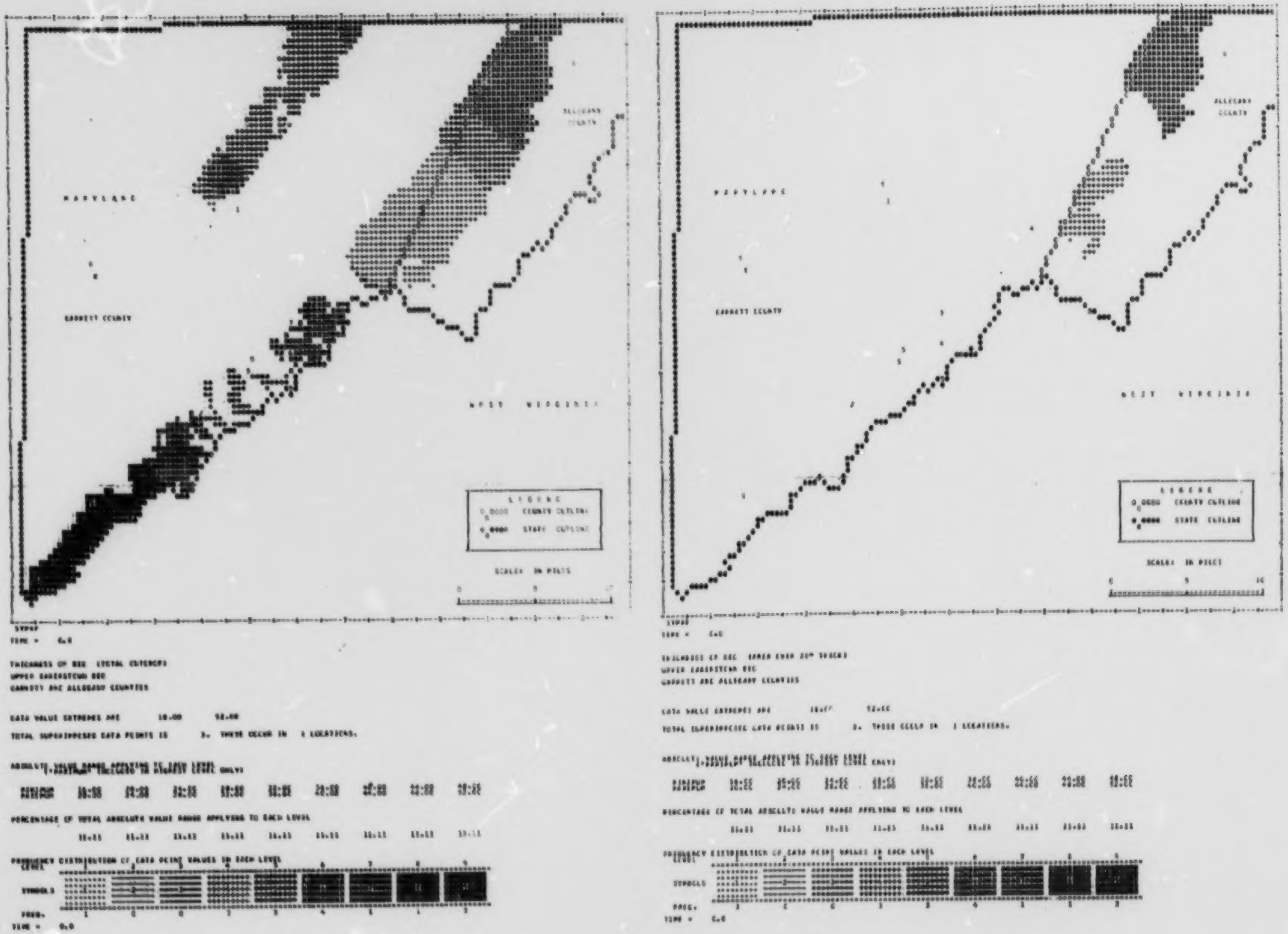
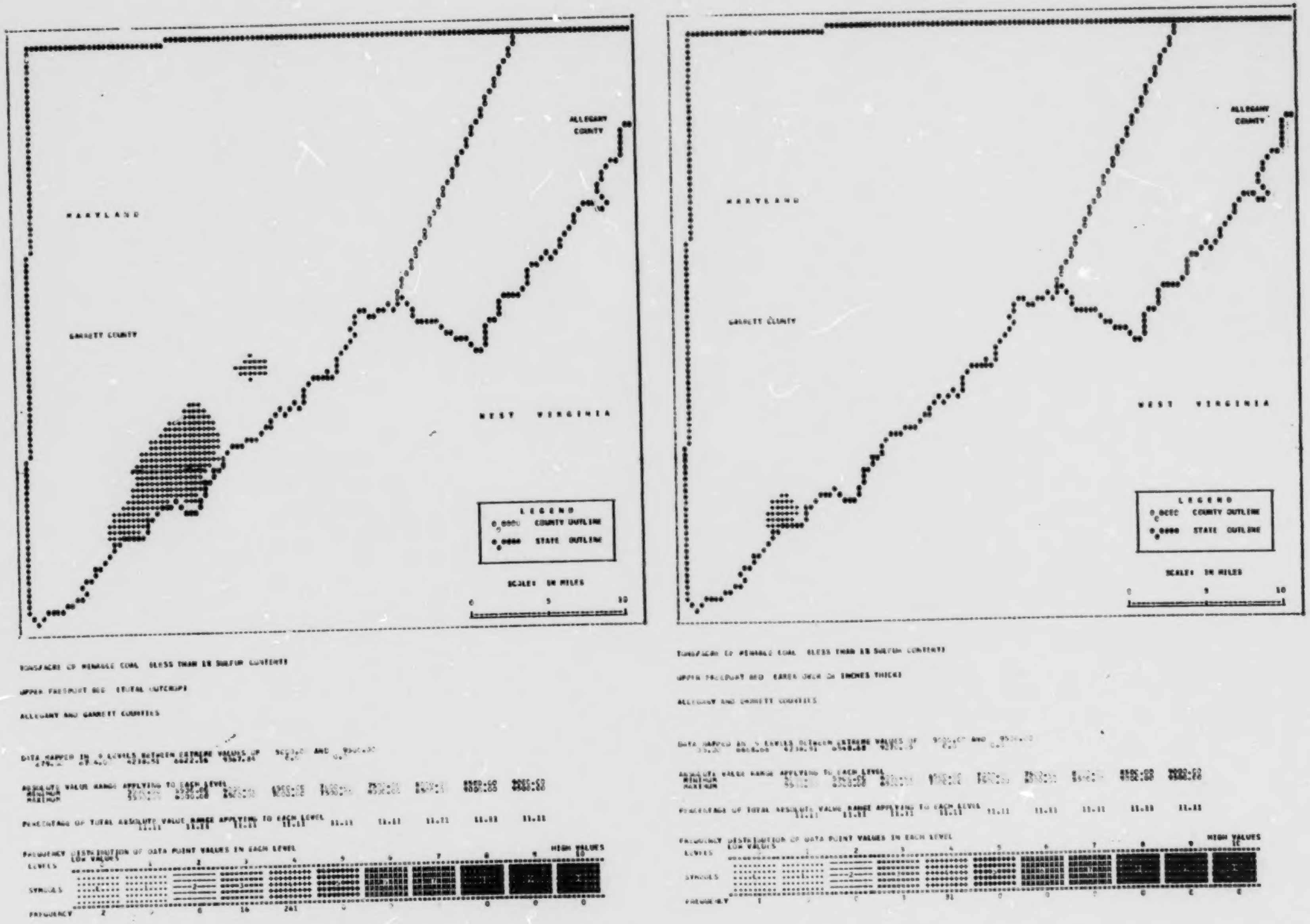

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
THICKNESS OF BED (TOTAL OUTCROP)
UPPER BAKERSTOWN BED
GARRETT AND ALLEGANY COUNTIES

Figure F-2
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Thickness of Bed
left: total outcrop; right: area over 28" thick



MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10

Figure F-3
Allegany and Garrett Counties
Upper Freeport Coal Bed
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

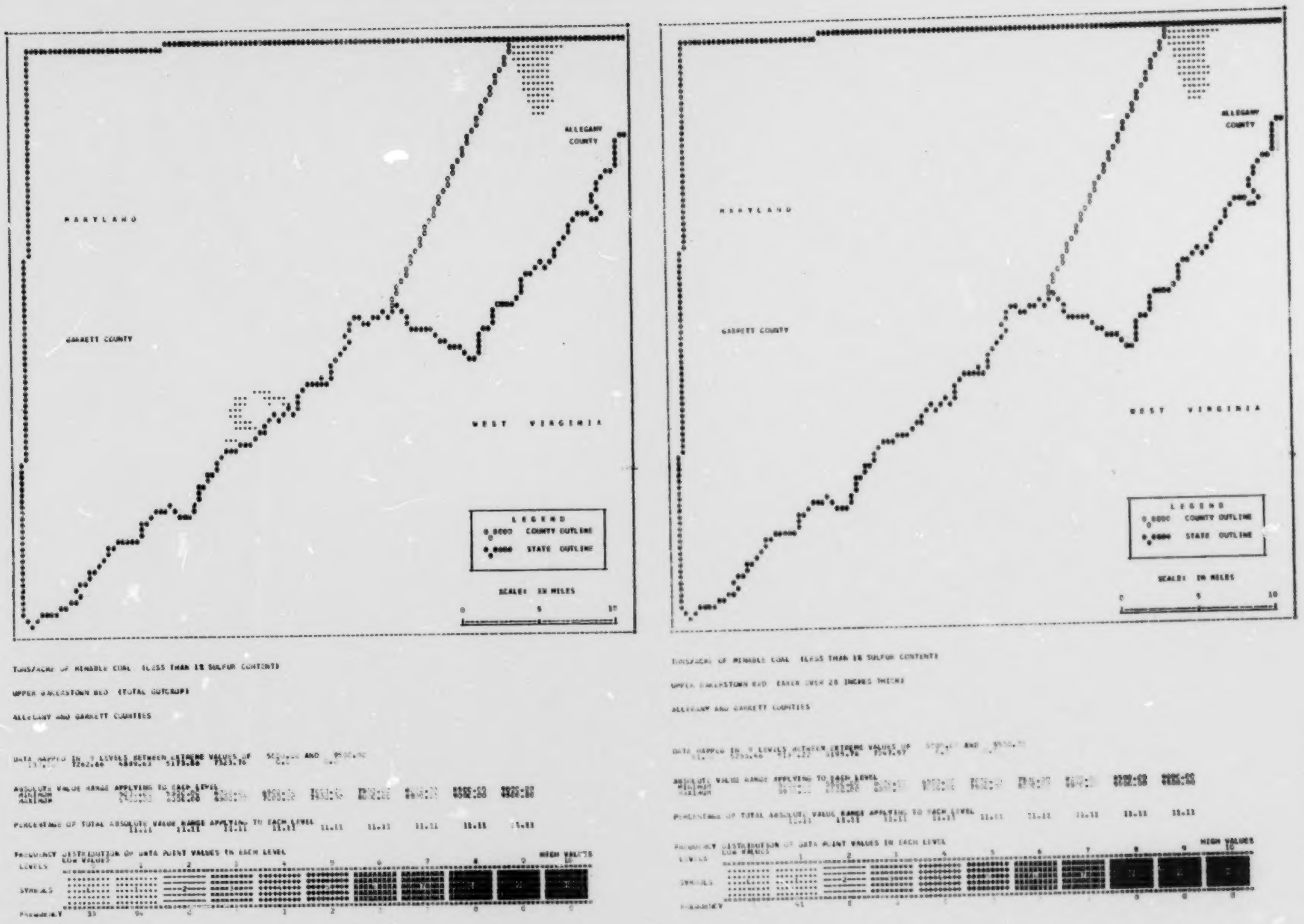

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
TONS/ACRE OF MINABLE COAL (LESS THAN 1% SULFUR CONTENT)
UPPER BAKERSTOWN BED (TOTAL OUTCROP)
ALLEGANY AND GARRETT COUNTIES
UPPER BAKERSTOWN BED (AREA OVER 28 INCHES THICK)
DATA MAPPED IN 9 LEVELS BETWEEN EXTREME VALUES OF
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LOW VALUES
HIGH VALUES
LEVELS
SYMBOLS
FREQUENCY

Figure F-4
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

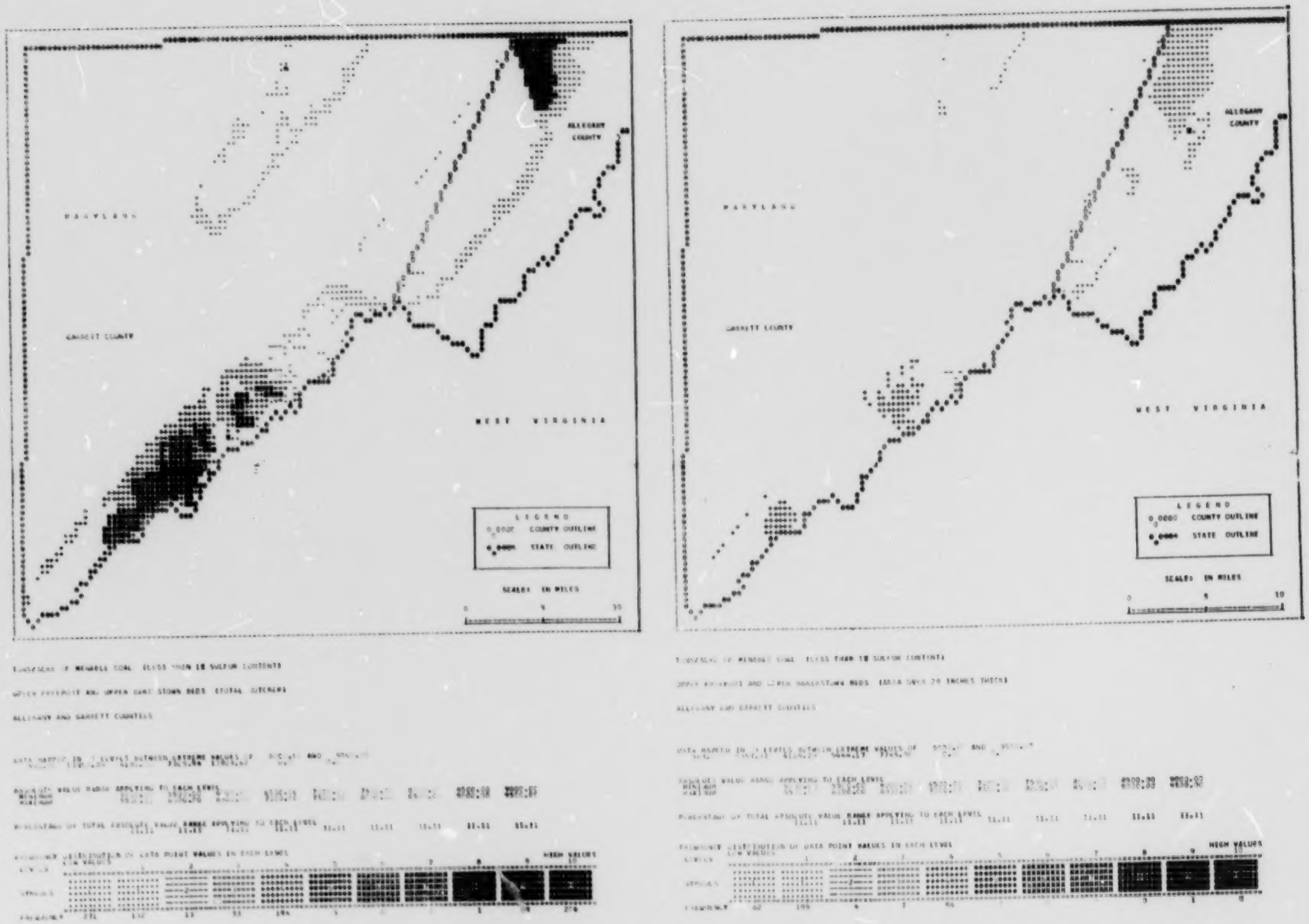

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
HIGH VALUES
LOW VALUES
1
2
3
4
5
6
7
8
9
10
MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
5
10
HIGH VALUES
LOW VALUES

Figure F-5
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

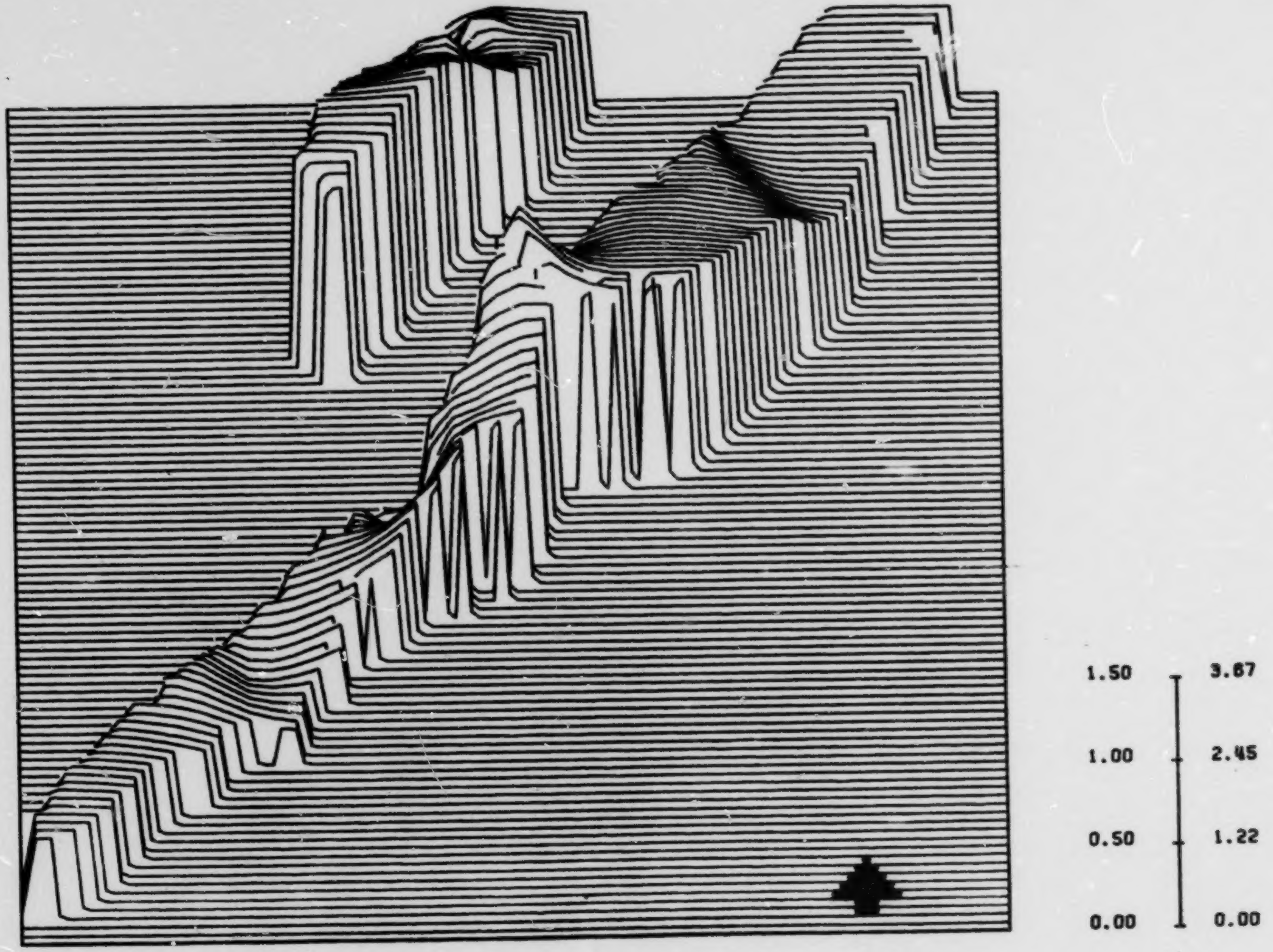


Figure F-6a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for total outcrop; azimuth 0°

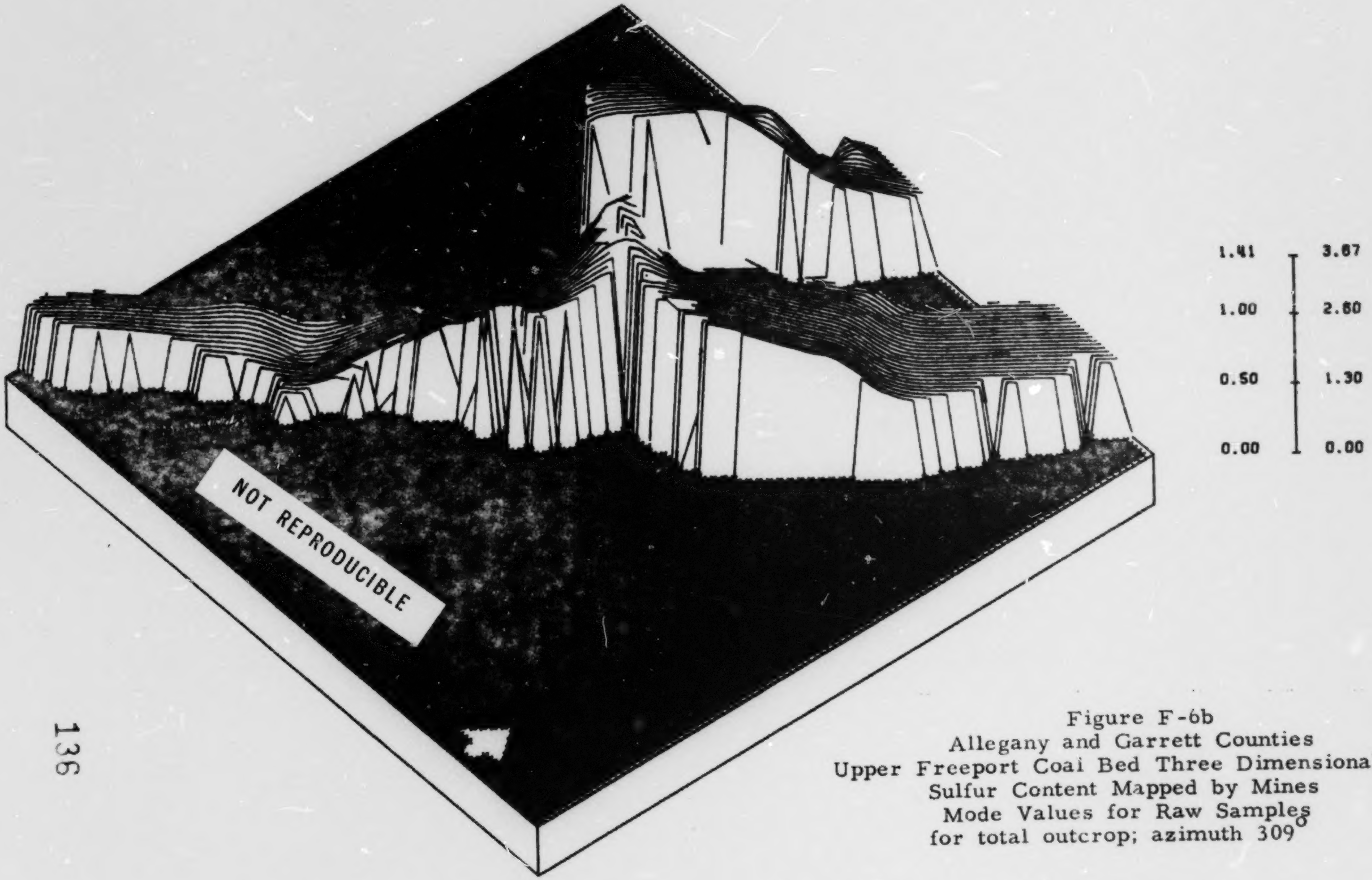

1.41
1.00
0.50
0.00
3.87
2.60
1.30
0.00
NOT REPRODUCIBLE

Figure F-6b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional Viev
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for total outcrop; azimuth 309°

U. FREEPORT BED (TOTAL OUTCROP), % SULFUR CONTENT (MODE), G&A CO.MARYLAN(

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/19/71

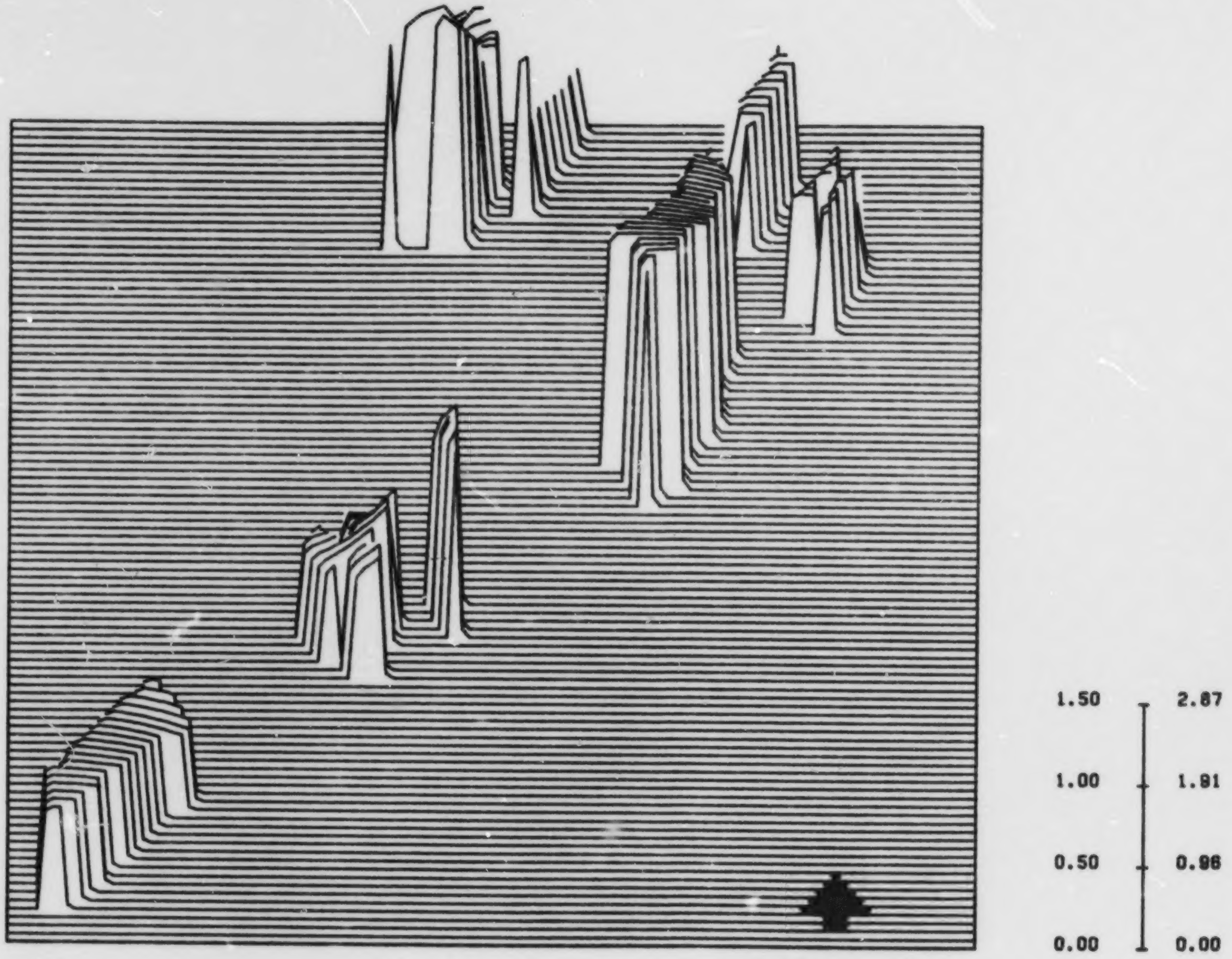


Figure F-7a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for area over 28"thick; azimuth 0°

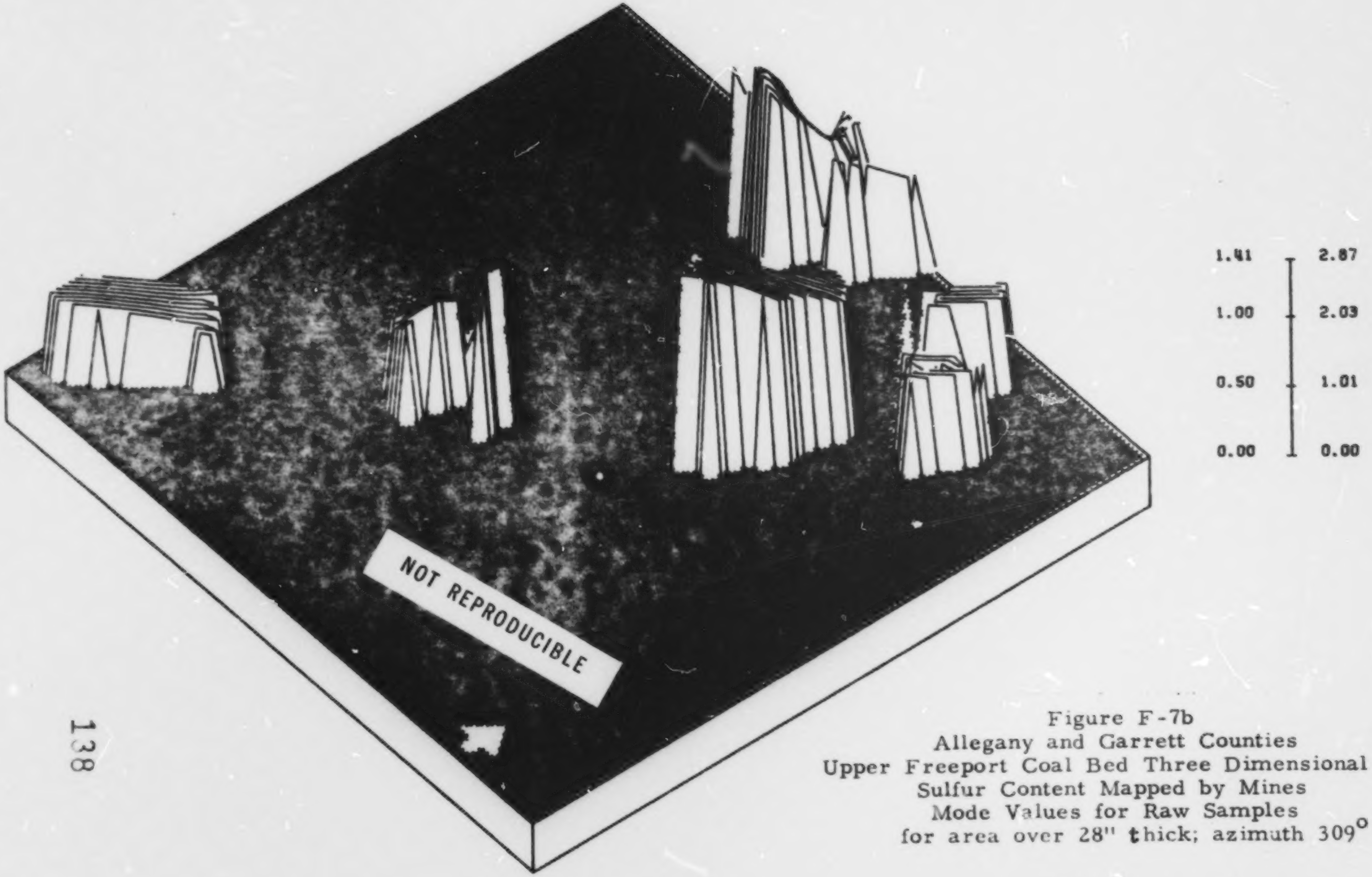


Figure F-7b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for area over 28" thick; azimuth 309°

U. FREEPORT BED (AREA >28"THICK),% SULFUR CONTENT (MODE),G&A CO.MARYLAND

AZIMUTH = 309
WIDTH = 6.00
ALTITUDE = 45
HEIGHT = 2.00

04/16/71

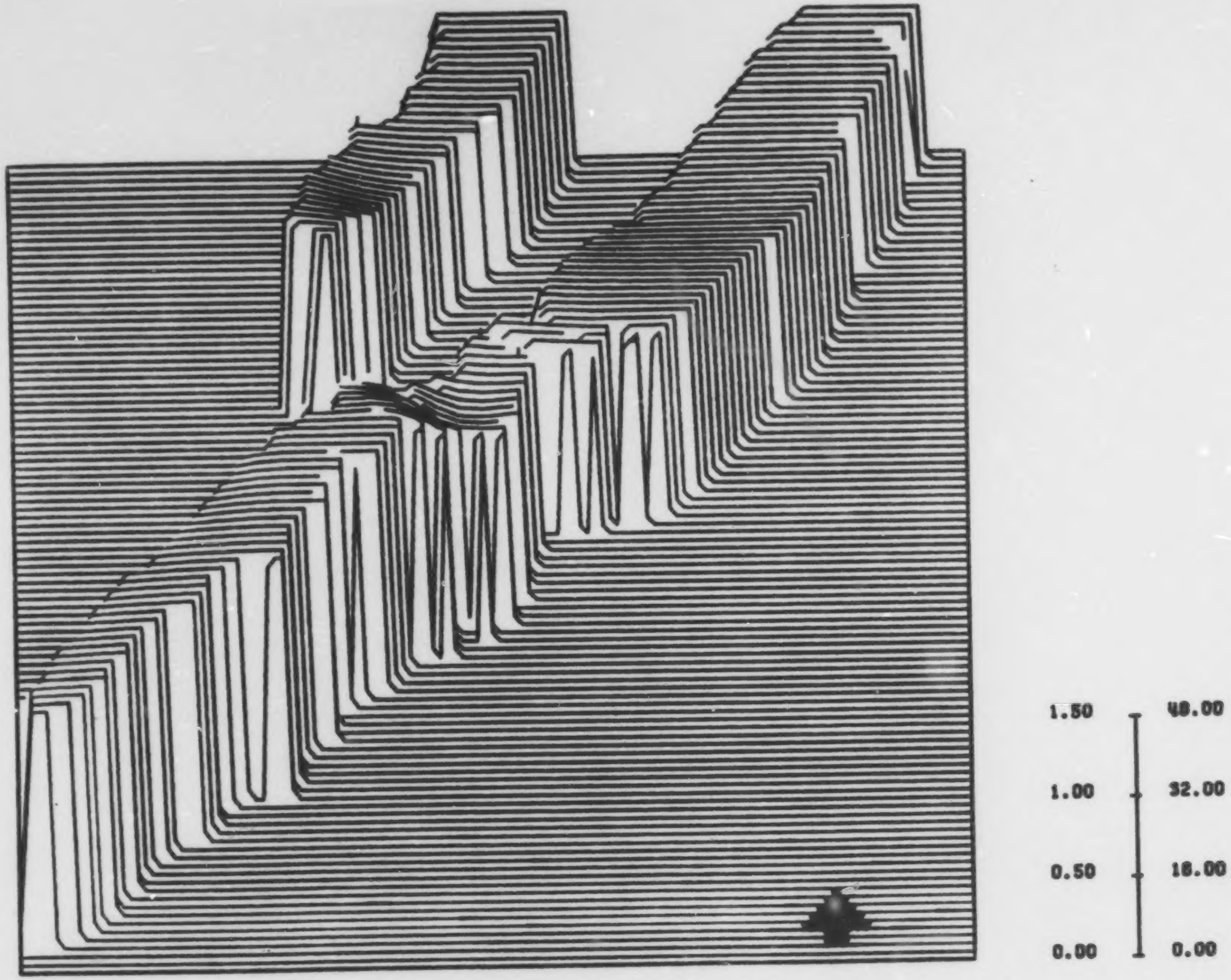


Figure F-8a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for total outcrop; azimuth 0°

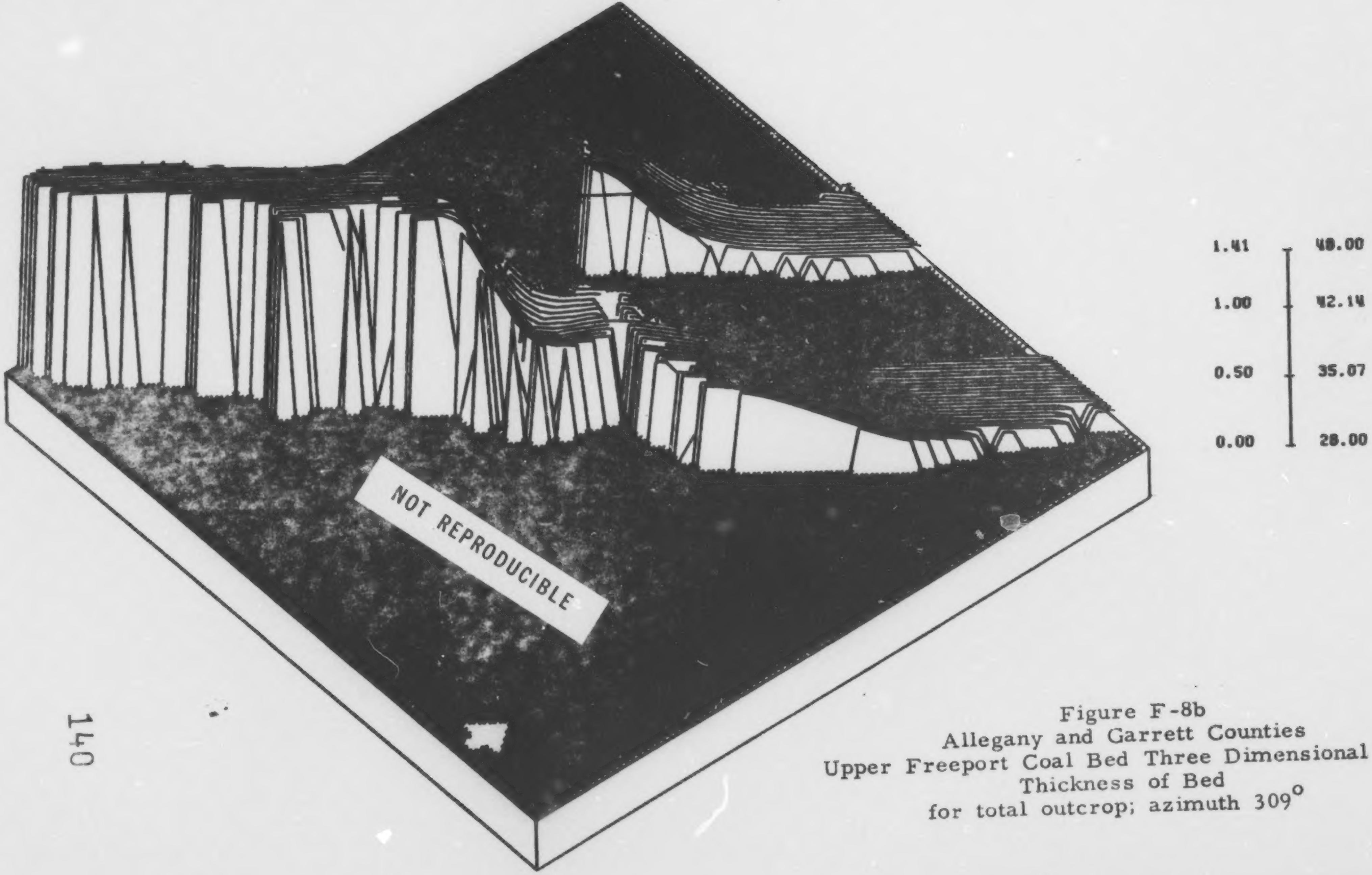

1.41
48.00
1.00
42.14
0.50
35.07
0.00
28.00
NOT REPRODUCIBLE

Figure F-8b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for total outcrop; azimuth 309°

U. FREEPORT BED, THICKNESS OF TOTAL OUTCROP, GARRETT&ALLEGANY CO. MARYLAN

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/16/71

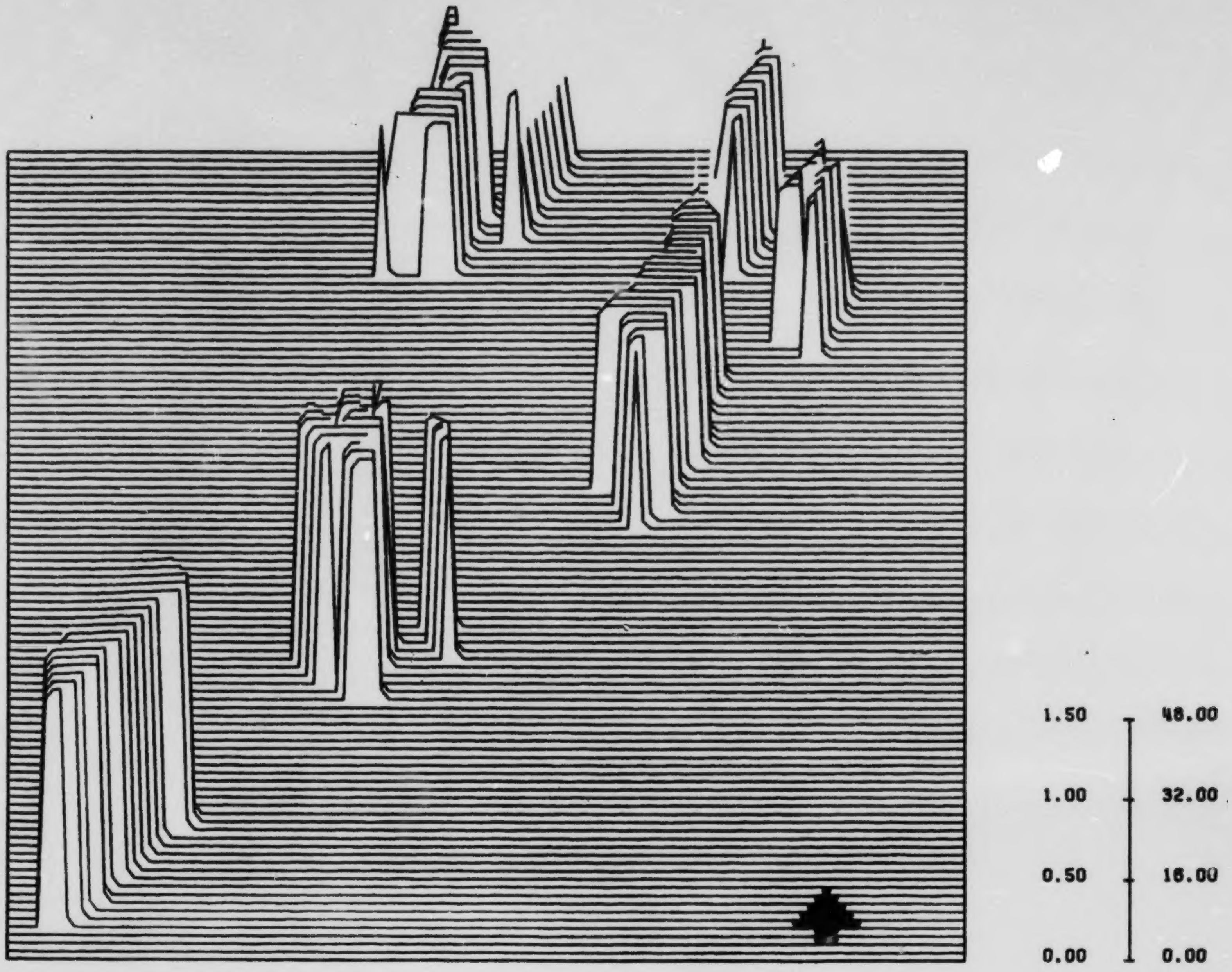


Figure F-9a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for area over 28" thick; azimuth 0°

NOT REPRODUCIBLE

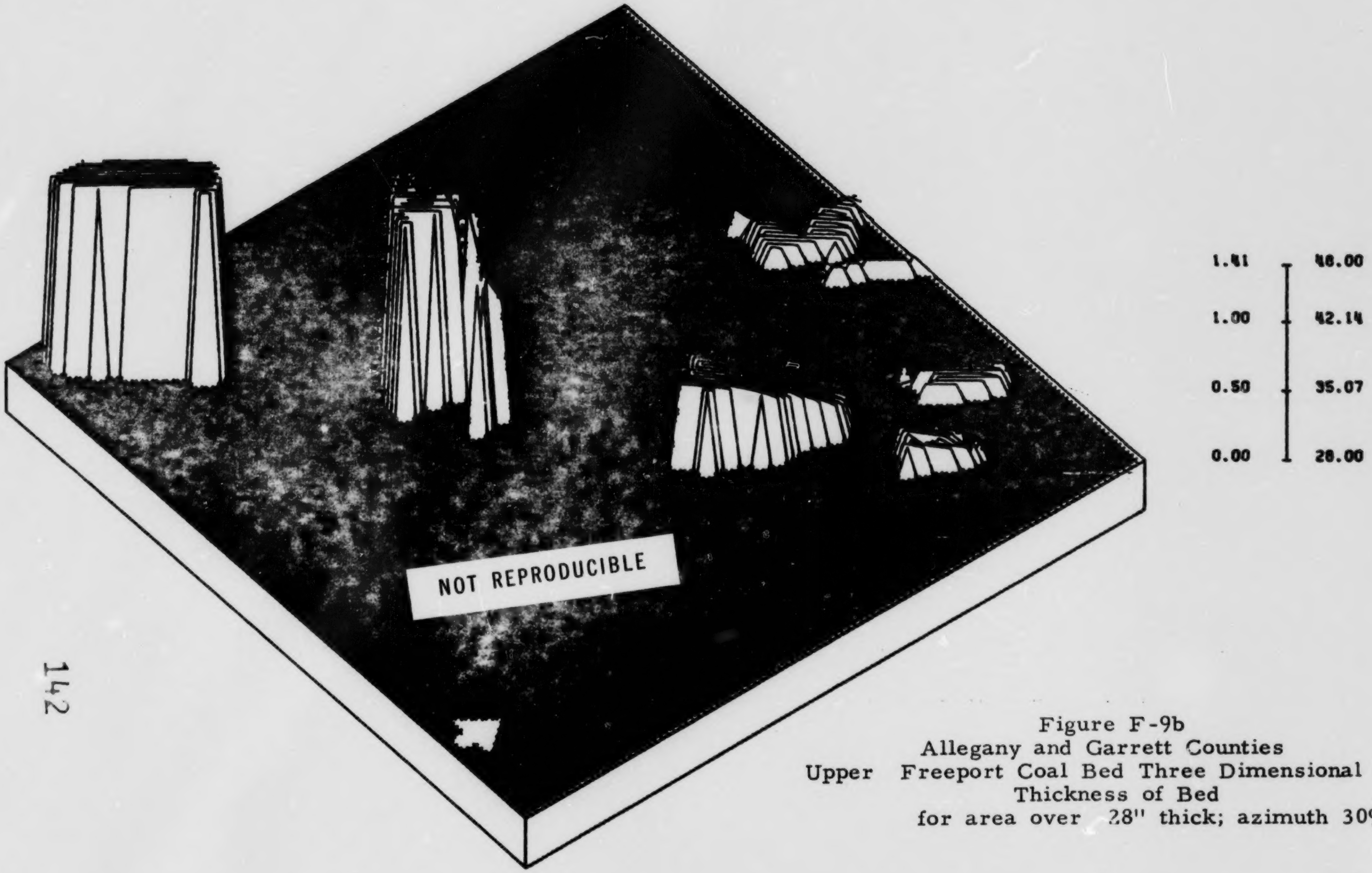
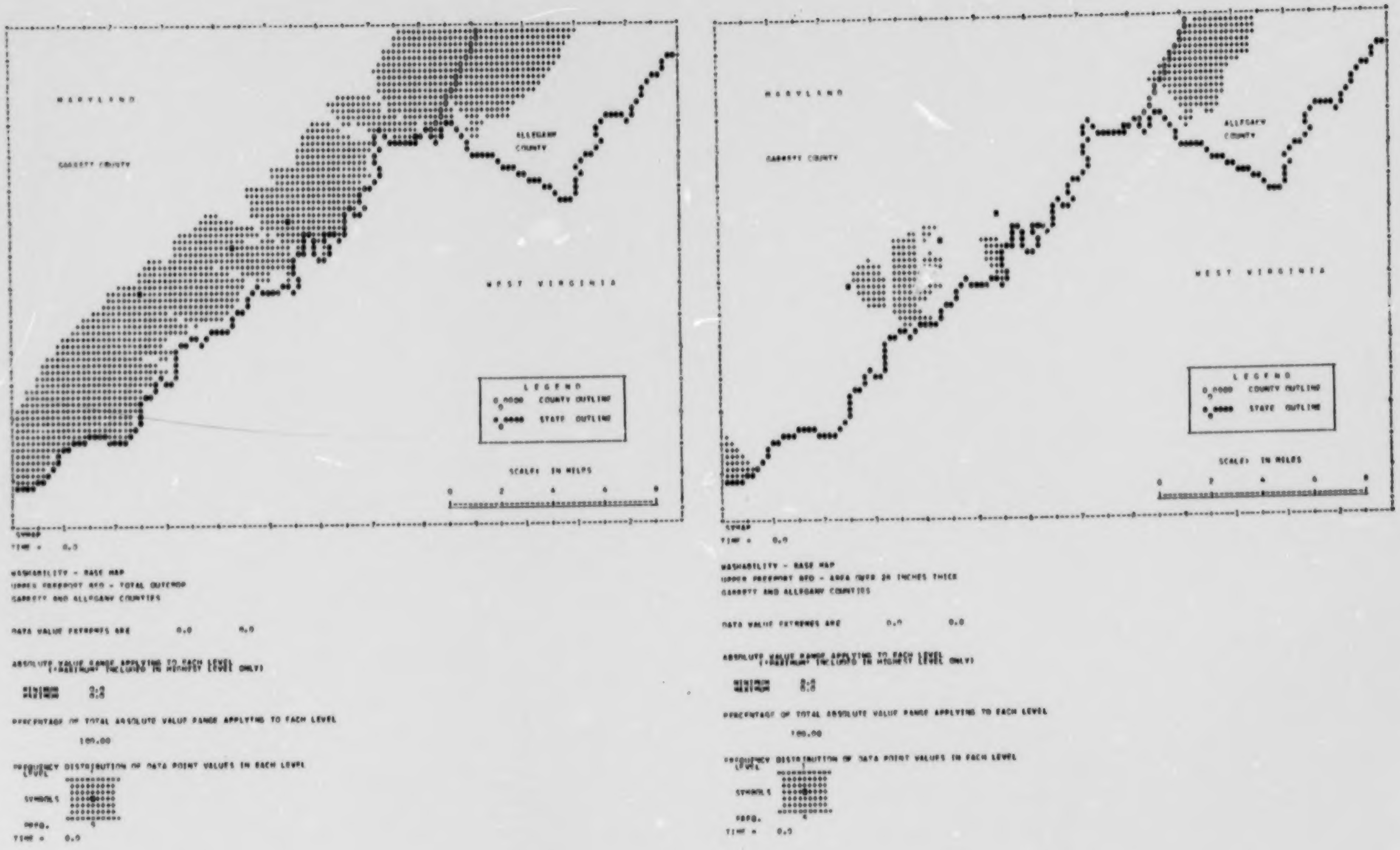

1.41
48.00
1.00
42.14
0.50
35.07
0.00
28.00
NOT REPRODUCIBLE

Figure F-9b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional Viev
Thickness of Bed
for area over 28" thick; azimuth 309°

U. FREEPORT BED,THICKNESS OF AREAS >28",GARRETT&ALLEGANY COUNTY,MARYLANI

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/16/71


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
2
4
6
8

```
SYMAP
TIME =    0.0

WASHABILITY - BASE MAP
UPPER FREEPORT BED - TOTAL OUTCROP
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      (MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM     0.0
  MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

           100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL

  SYMBOLS

  FREQ.
TIME =    0.0
```

```
SYMAP
TIME =    0.0

WASHABILITY - BASE MAP
UPPER FREEPORT BED - AREA OVER 28 INCHES THICK
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.0        0.0

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      (MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM     0.0
  MAXIMUM     0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

           100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1

  SYMBOLS

  FREQ.        4
TIME =    0.0
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Figure G-1
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
Base Map of Samples
Left: total outcrop; right: area over 28" thick

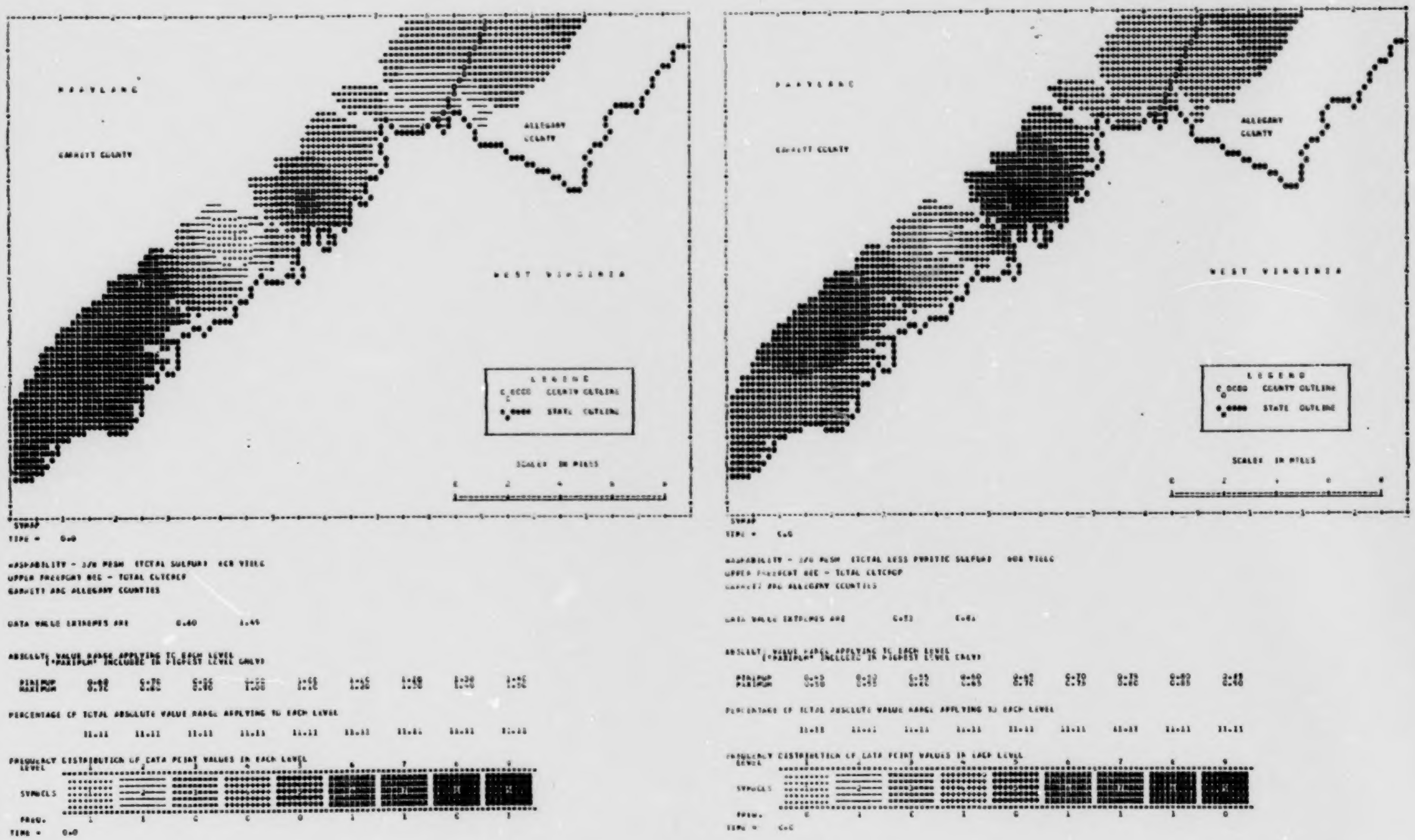
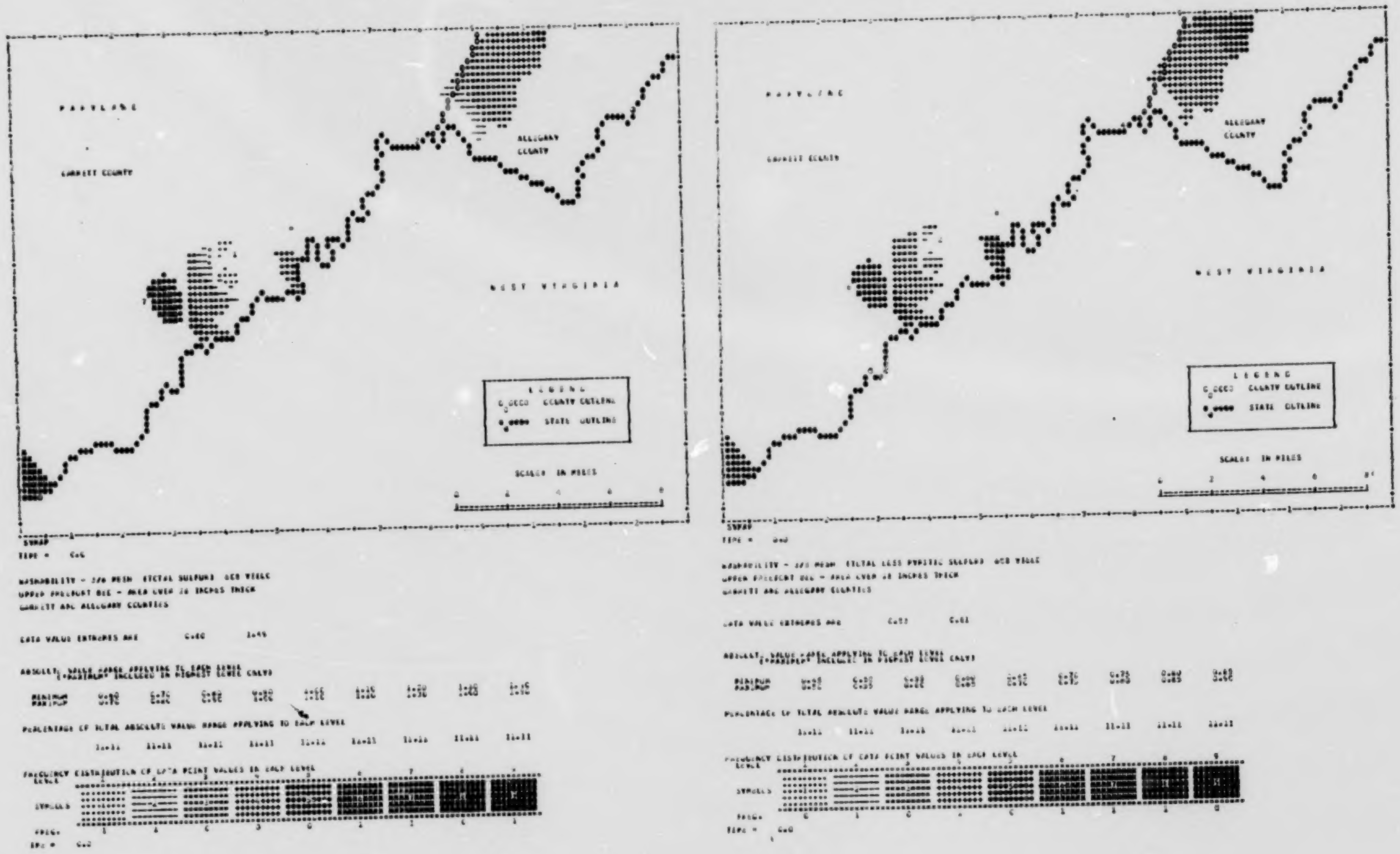

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
SYMAP
SYMBOLS
FREQ.

Figure G-2
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
3/8" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur



MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure G-3
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

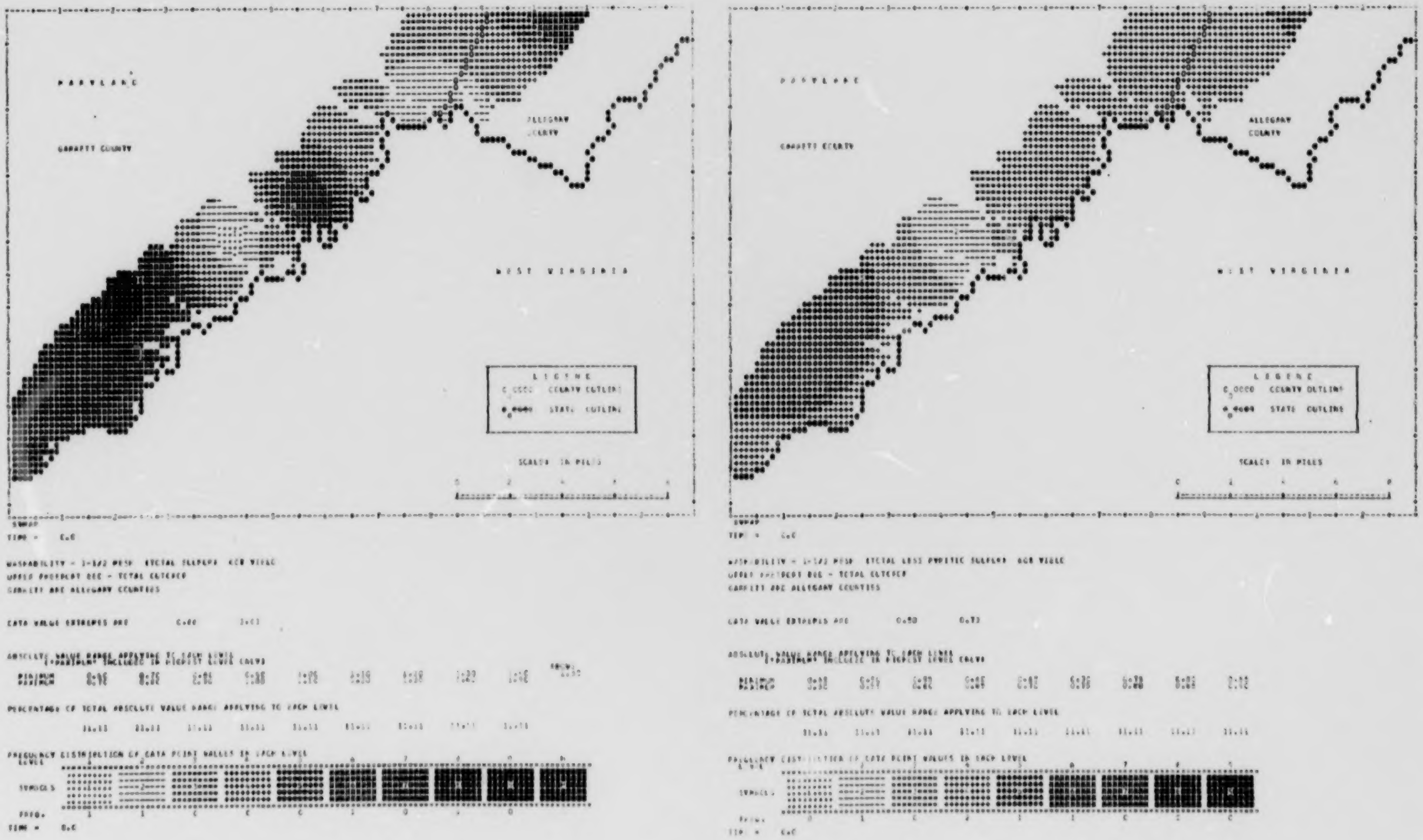
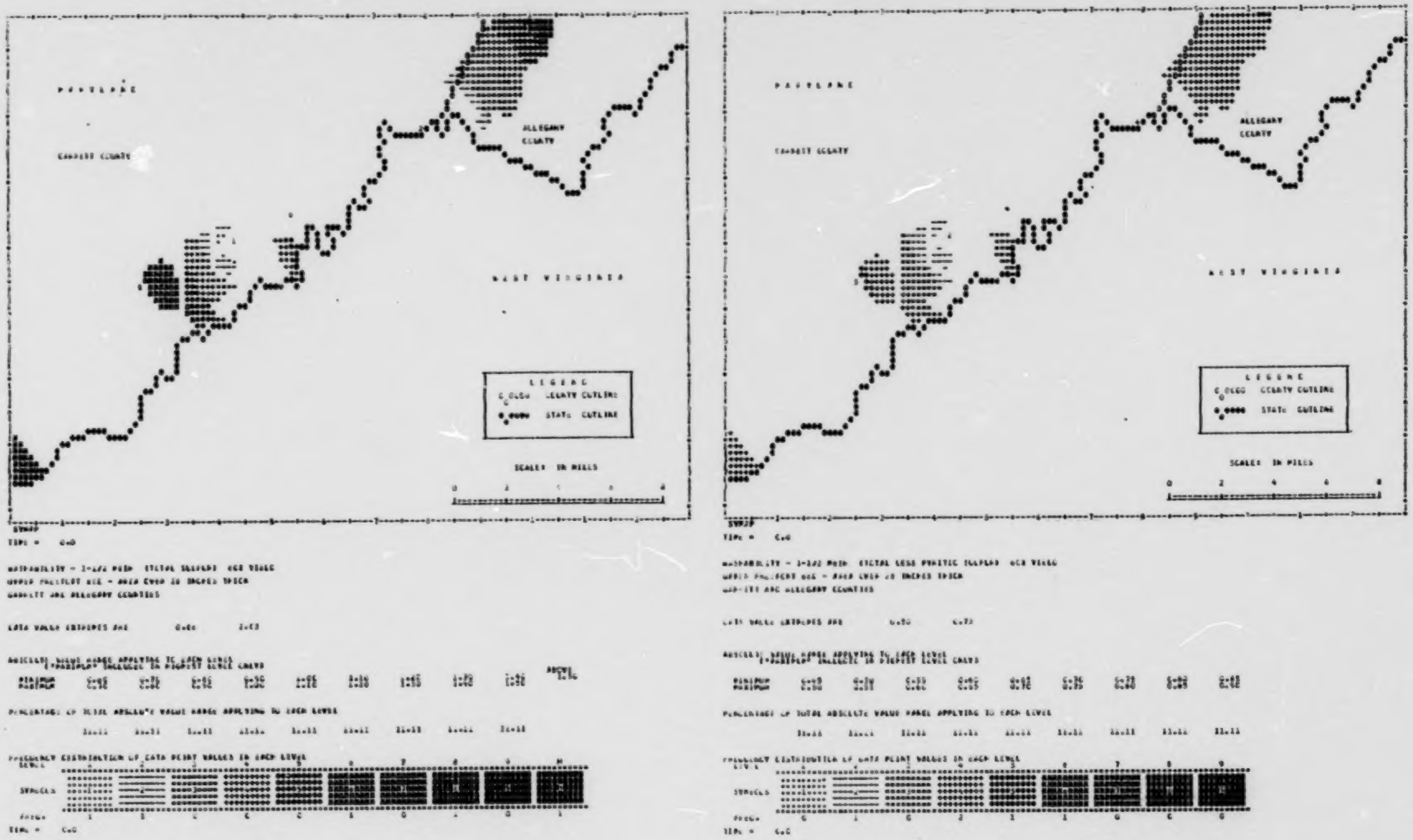

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure G-4
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
1 1/2" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur


MARYLAND
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ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALES IN MILES
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6
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MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALES IN MILES
0
2
4
6
8

Figure G-5
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
1 1/2" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

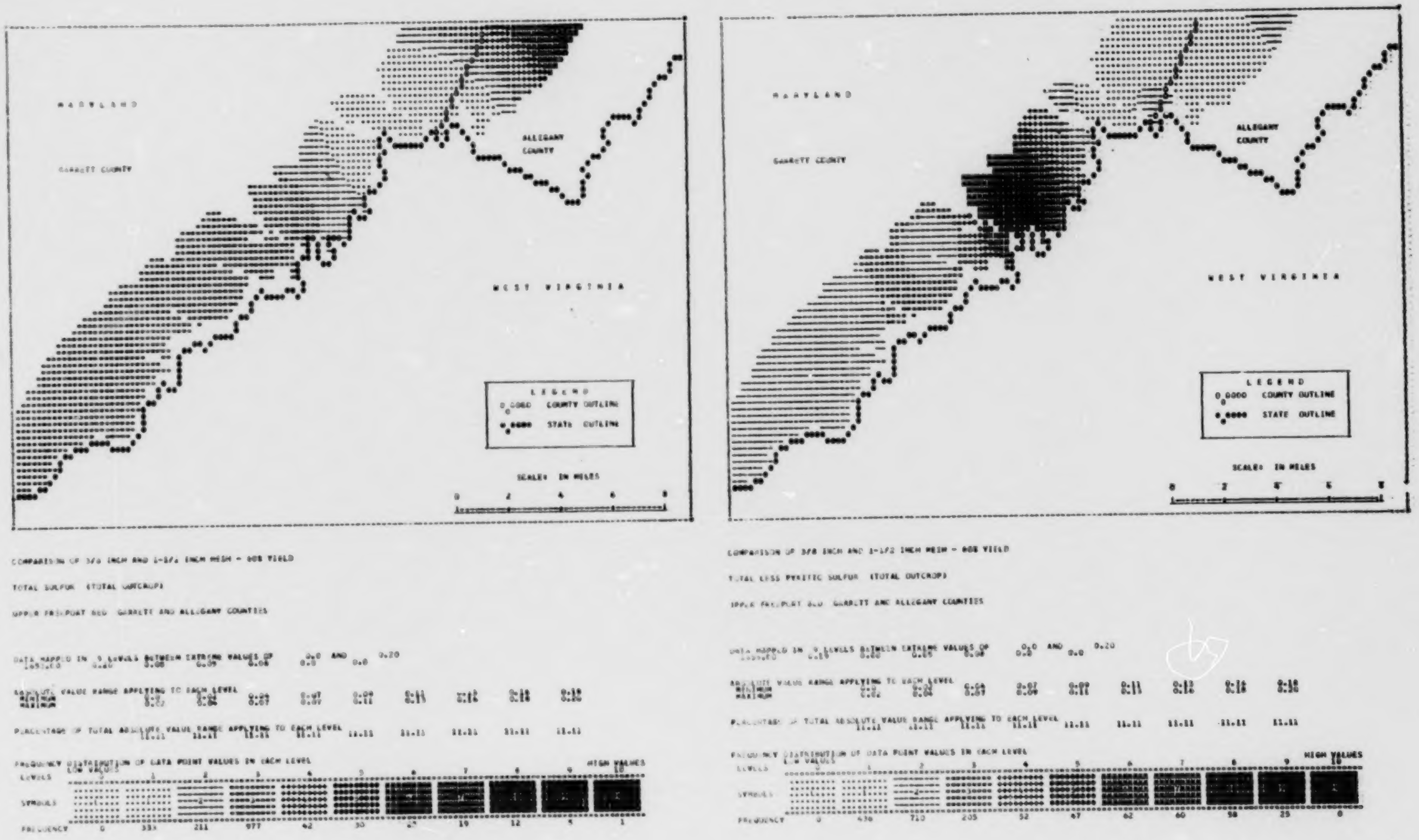

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0 2 4 6 8
COMPARISON OF 3/8 INCH AND 1-1/2 INCH MESH - 60% YIELD
TOTAL SULFUR (TOTAL OUTCROP)
TOTAL LESS PYRITIC SULFUR (TOTAL OUTCROP)
UPPER FREEPORT BED GARRETT AND ALLEGANY COUNTIES
LEVELS
SYMBOLS
FREQUENCY
LOW VALUES
HIGH VALUES

Figure G-6
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
Comparison of 3/8" and 1 1/2" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur

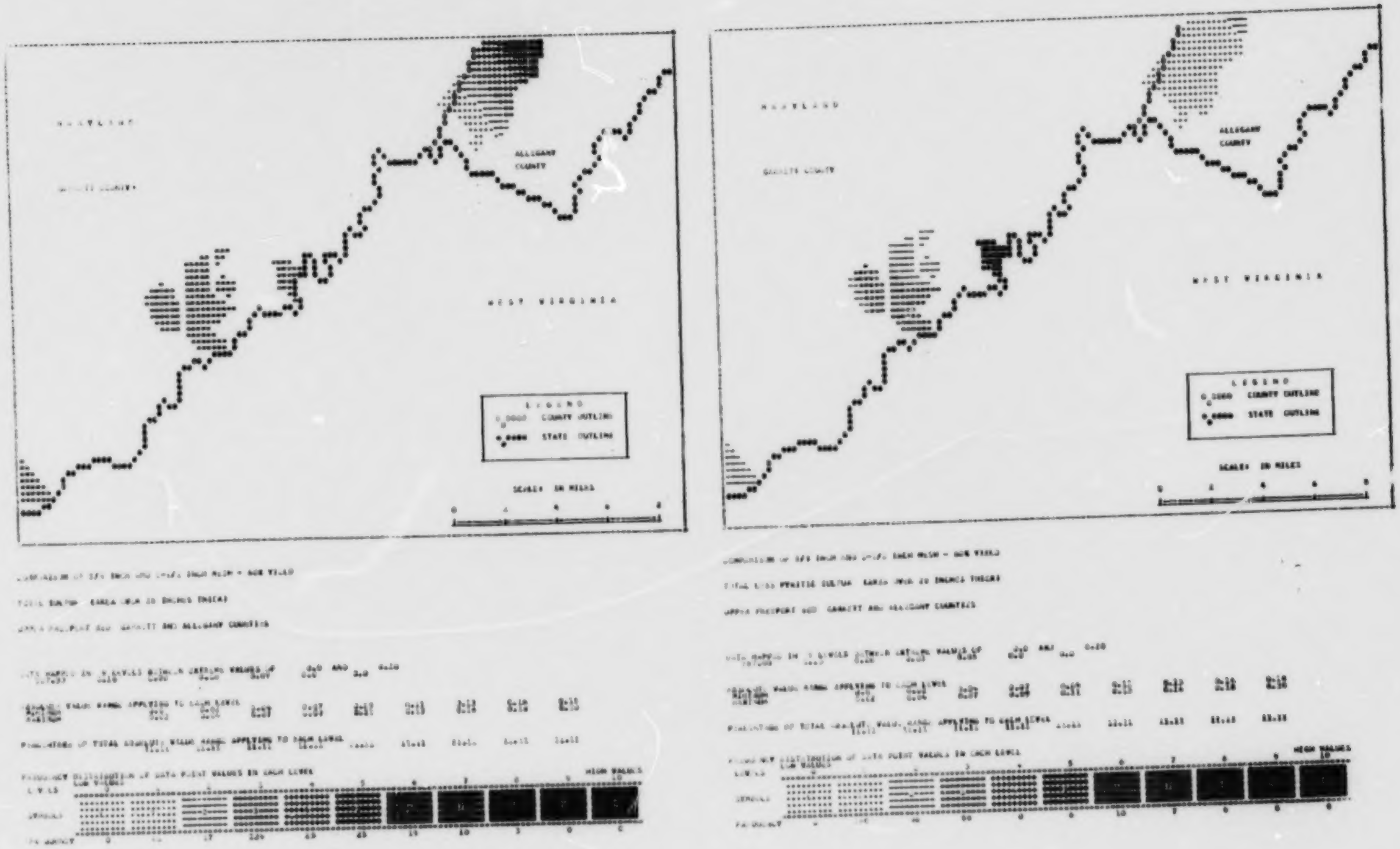

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
2
4
6
8
LOW VALUES
HIGH VALUES

Figure G-7
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
Comparison of 3/8" and 1 1/2" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

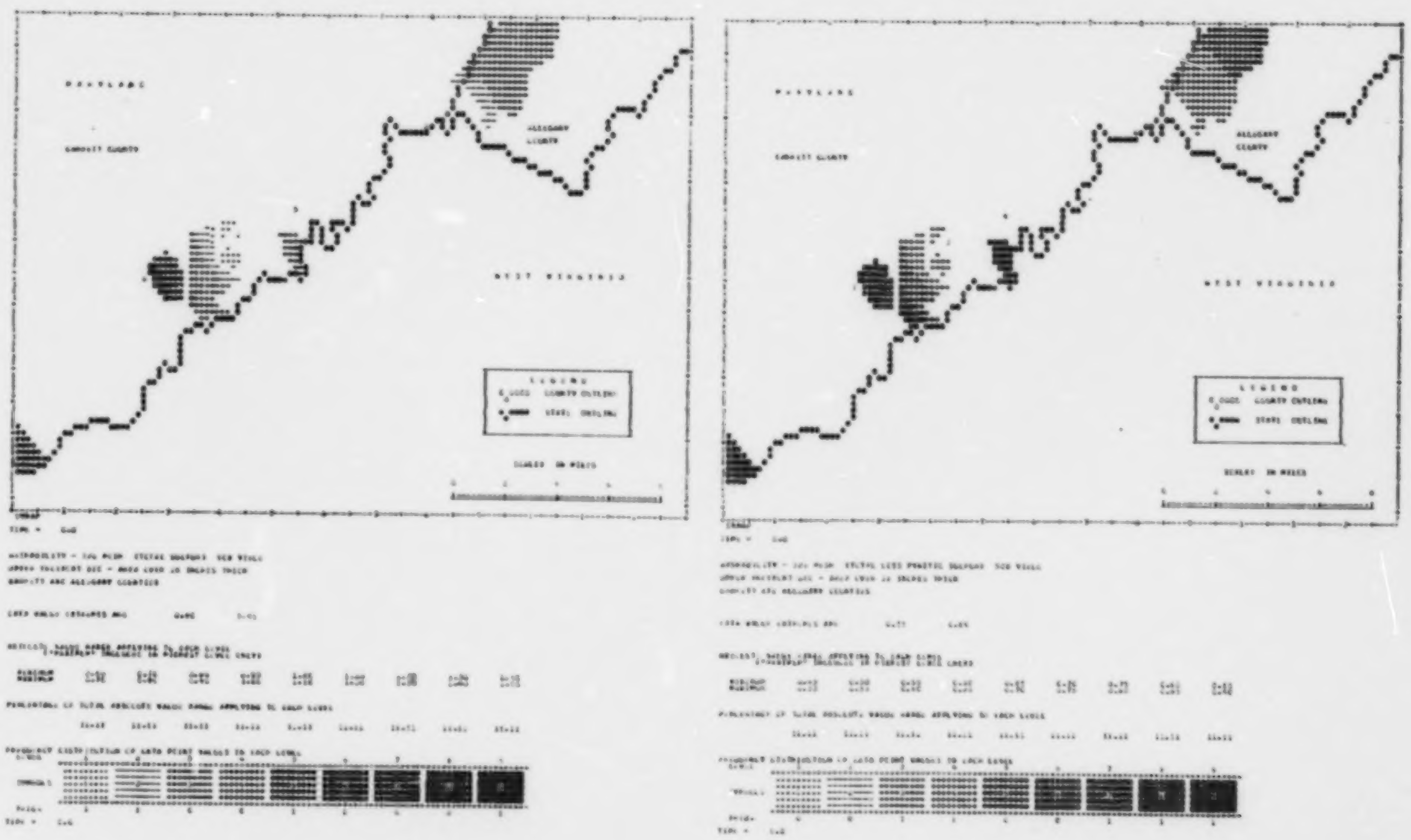

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure G-8
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 50% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

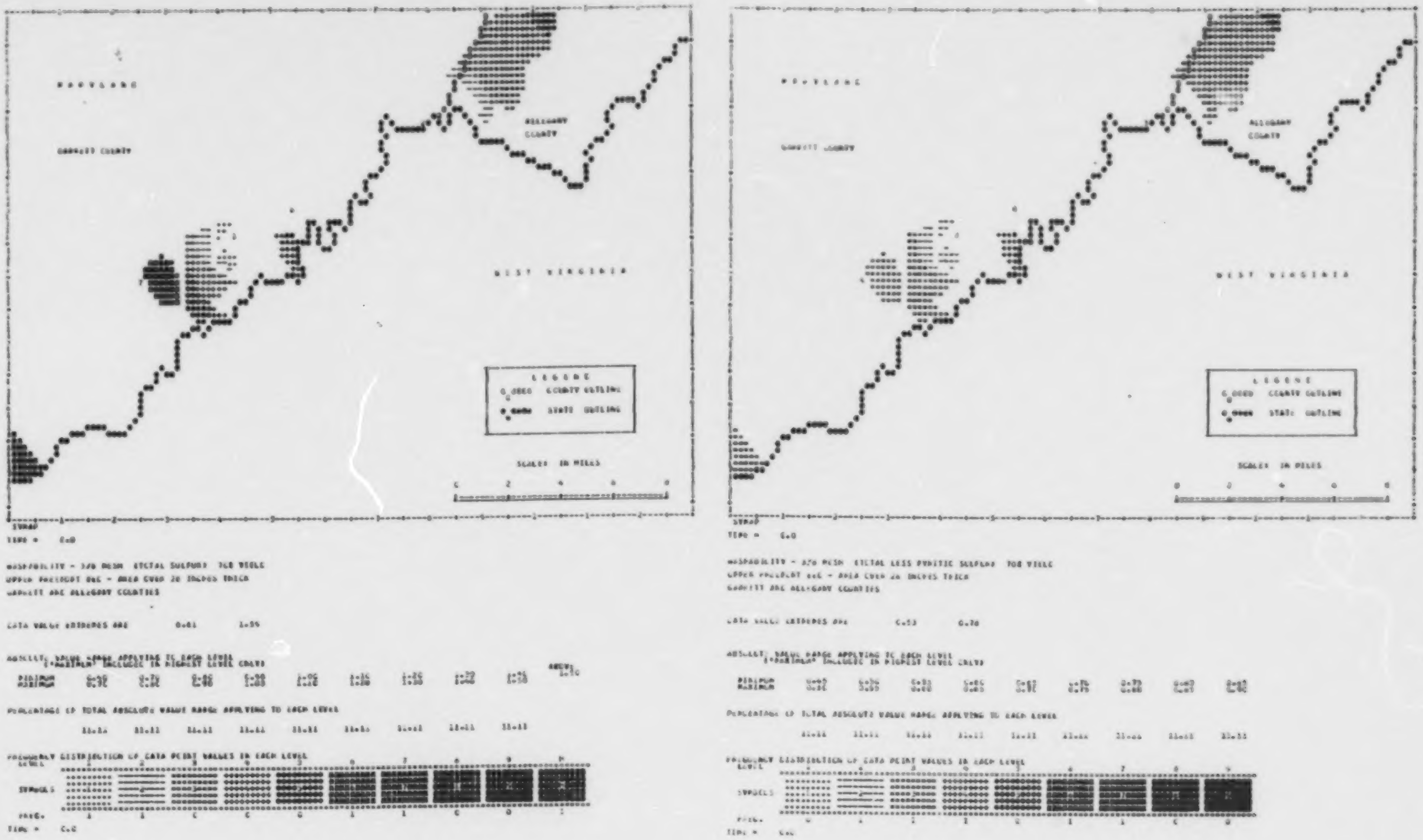

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES

Figure G-9
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 70% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

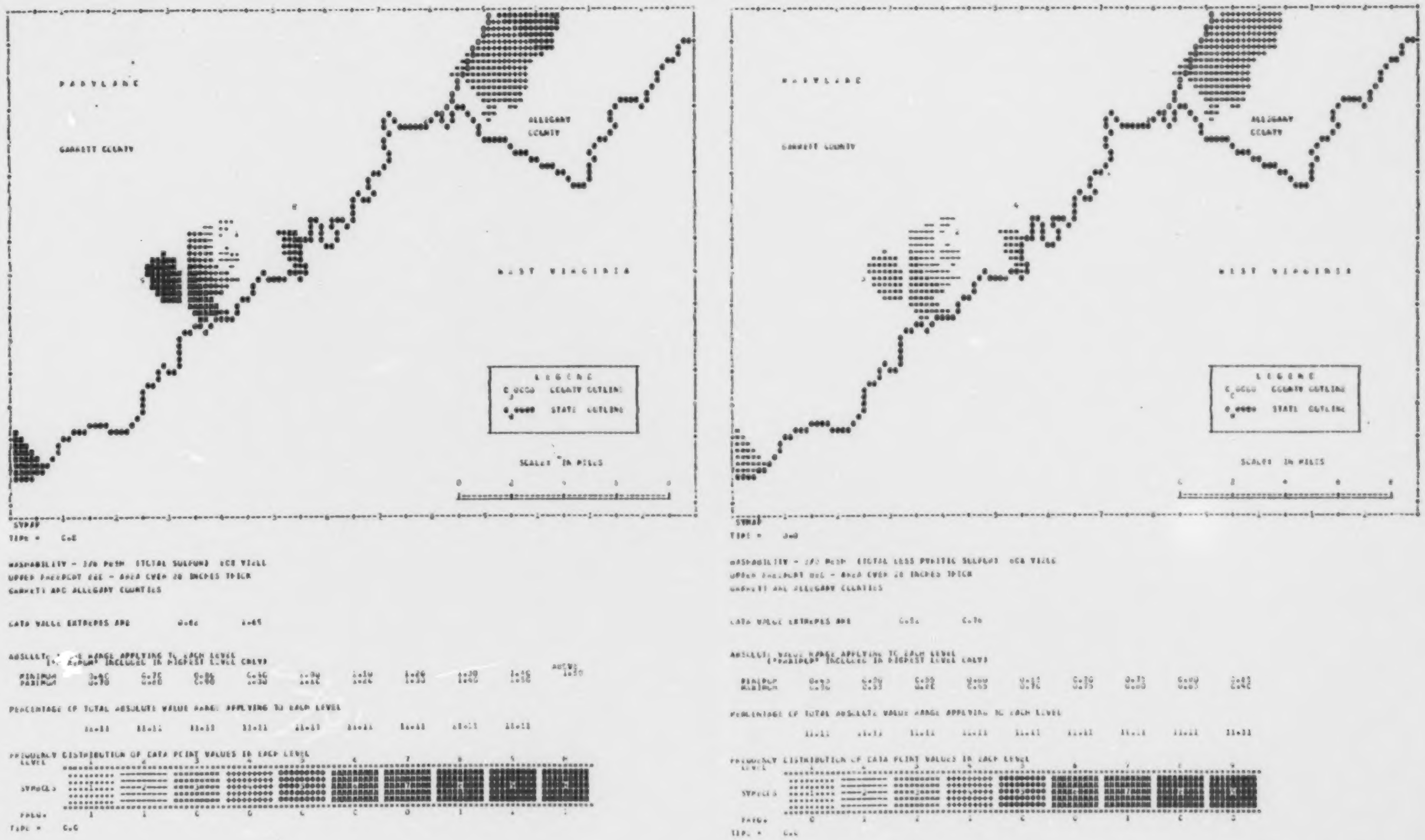


Figure G-10
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 80% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

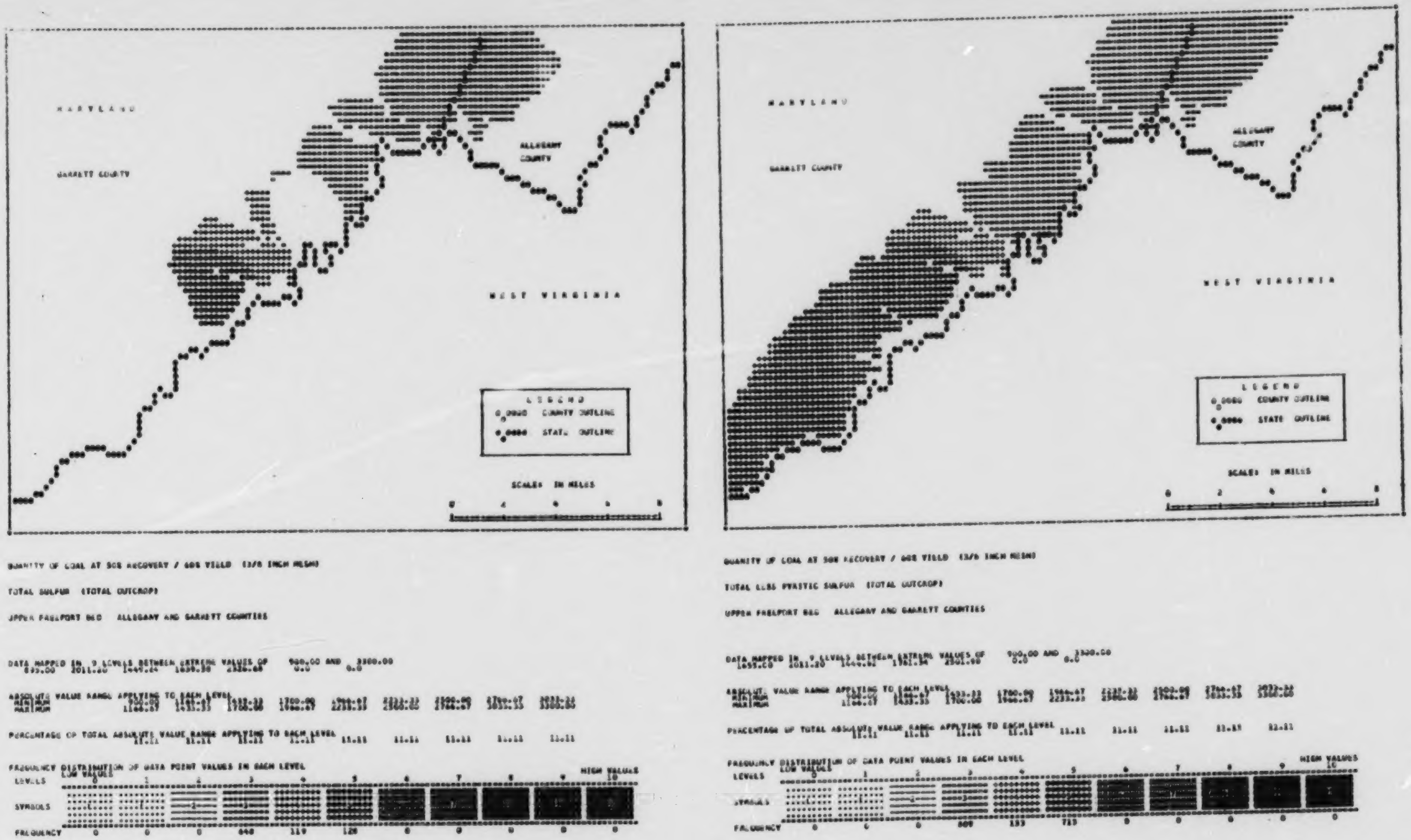
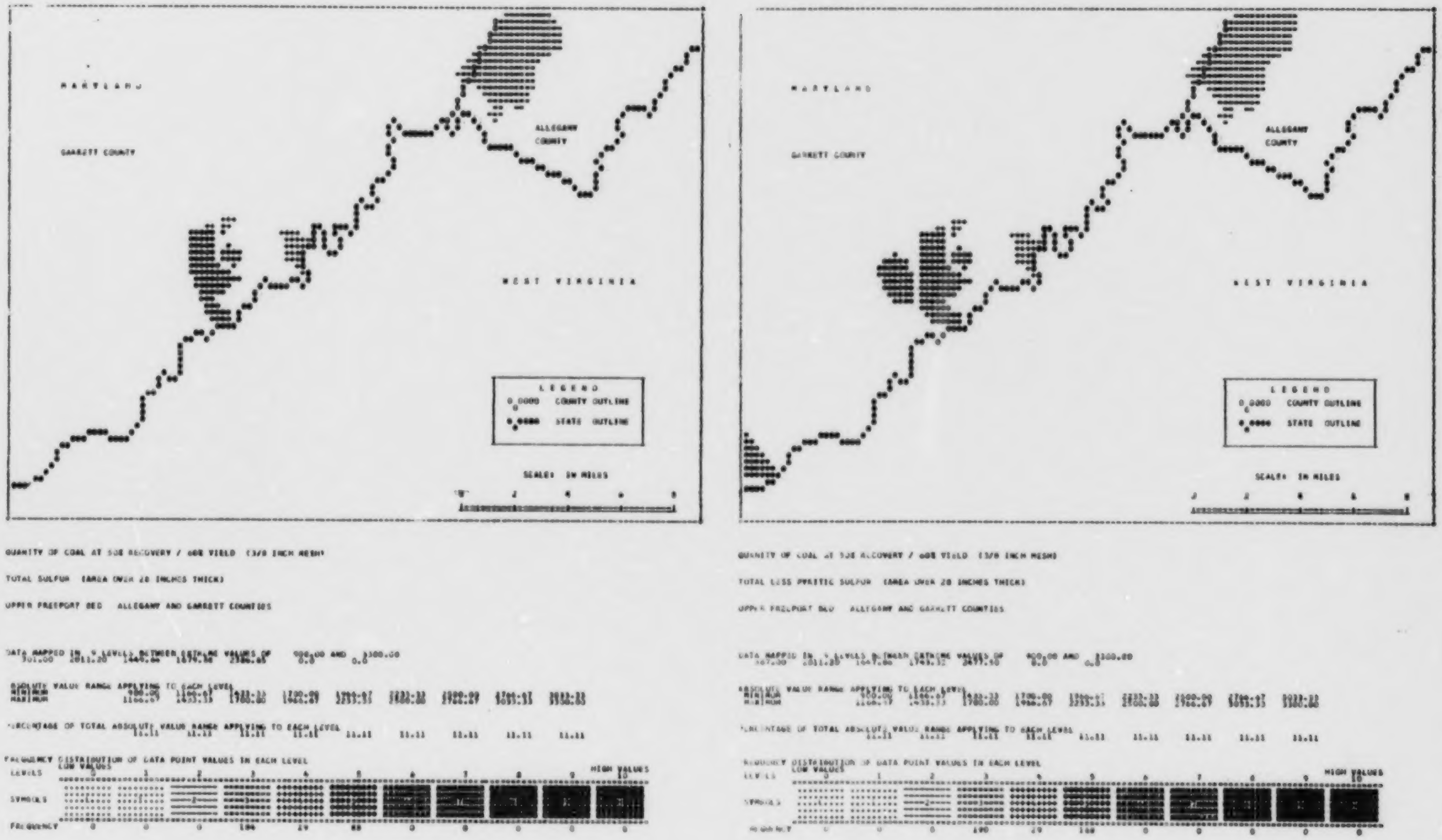

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALES IN MILES
QUANTITY OF COAL AT 50% RECOVERY / 60% YIELD (3/8 INCH MESH)
TOTAL SULFUR (TOTAL OUTCROP)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
QUANTITY OF COAL AT 50% RECOVERY / 60% YIELD (3/8 INCH MESH)
TOTAL LESS PYRITIC SULFUR (TOTAL OUTCROP)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
DATA MAPPED IN 9 LEVELS BETWEEN EXTREME VALUES OF
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LOW VALUES
HIGH VALUES
LEVELS
SYMBOLS
FREQUENCY

Figure H-1
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 60% yield
3/8" mesh; for total outcrop
left: total sulfur; right: total less pyrific sulfur


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
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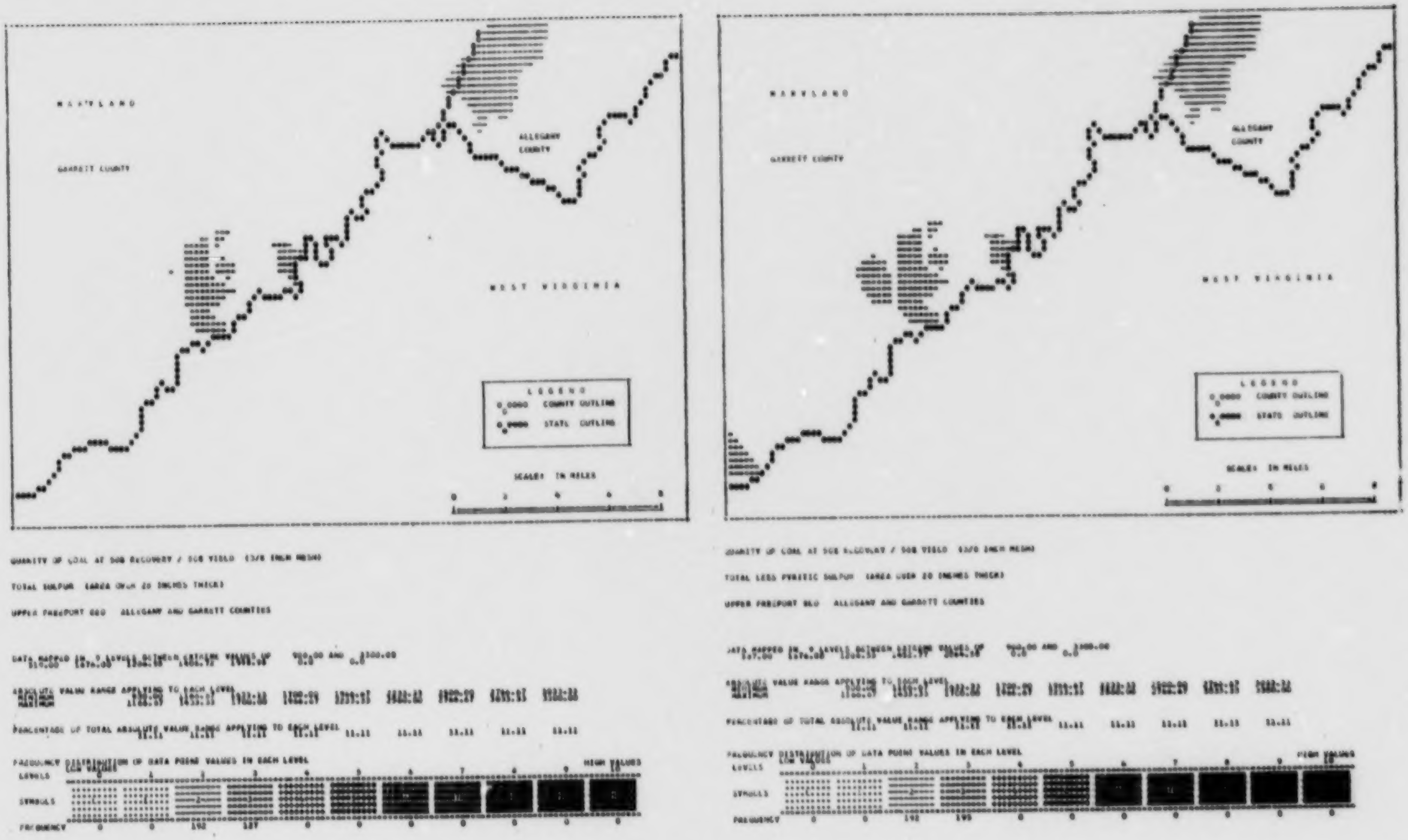
8
QUANTITY OF COAL AT 50% RECOVERY / 60% YIELD (3/8 INCH MESH)
TOTAL SULFUR (AREA OVER 28 INCHES THICK)
TOTAL LESS PYRITIC SULFUR (AREA OVER 28 INCHES THICK)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
DATA MAPPED IN 9 LEVELS BETWEEN DATUM VALUES OF
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVELS
LOW VALUES
HIGH VALUES
SYMBOLS
FREQUENCY

Figure H-2
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 60% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
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8
QUANTITY OF COAL AT 50% RECOVERY / 50% YIELD (3/8 INCH MESH)
TOTAL SULFUR (AREA OVER 28 INCHES THICK)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LOW VALUES
HIGH VALUES
LEVELS
SYMBOLS
FREQUENCY
TOTAL LESS PYRITIC SULFUR (AREA OVER 28 INCHES THICK)

Figure H-3
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 50% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

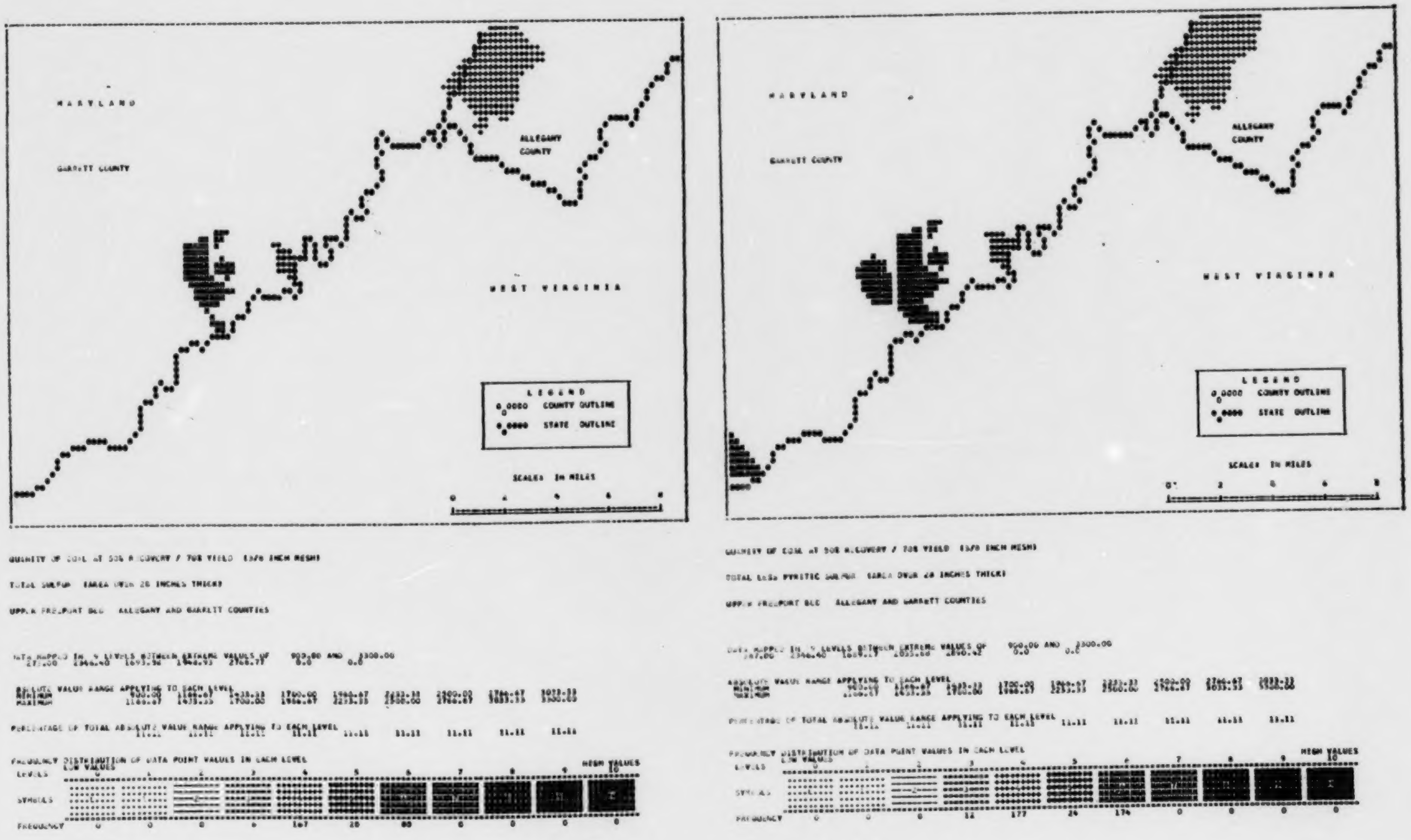

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALES IN MILES
0
2
4
6
8
QUANTITY OF COAL AT 50% RECOVERY / 70% YIELD (3/8 INCH MESH)
TOTAL SULFUR (AREA OVER 28 INCHES THICK)
TOTAL LESS PYRITIC SULFUR (AREA OVER 28 INCHES THICK)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LOW VALUES
HIGH VALUES
LEVELS
SYMBOLS
FREQUENCY

Figure H-4
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 70% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

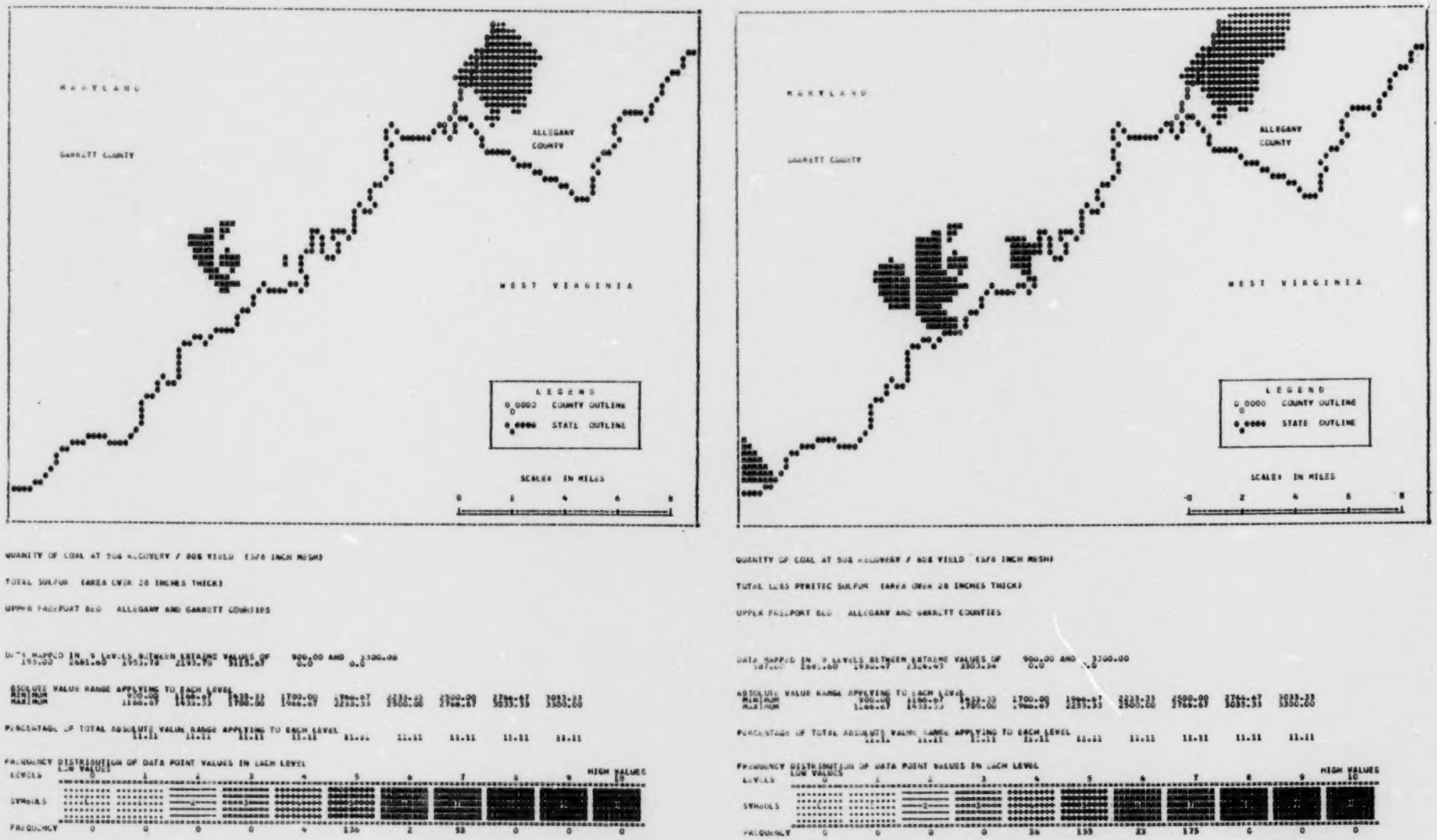
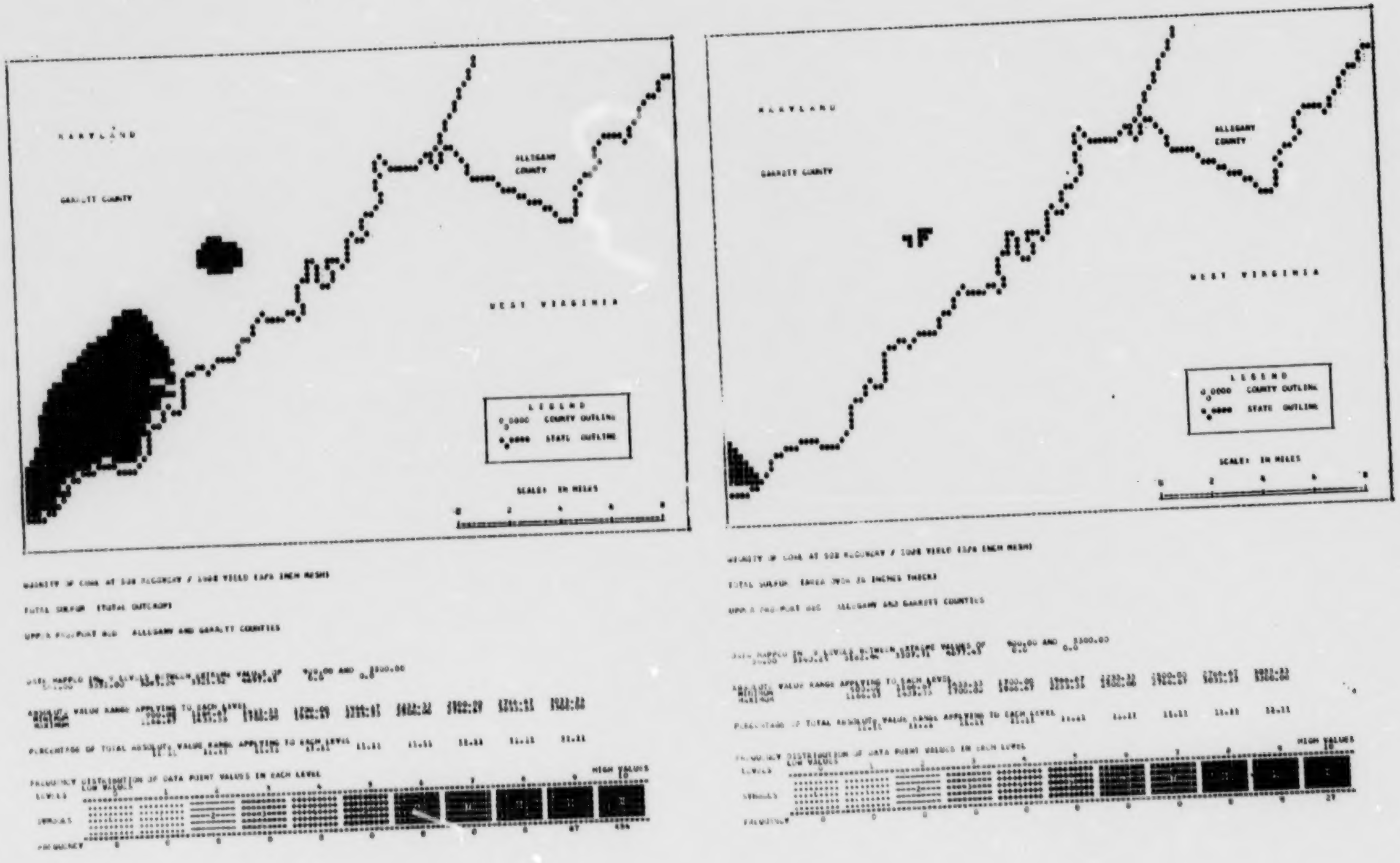

MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
QUANTITY OF COAL AT 50% RECOVERY / 80% YIELD (3/8 INCH MESH)
TOTAL SULFUR (AREA OVER 28 INCHES THICK)
TOTAL LESS PYRITIC SULFUR (AREA OVER 28 INCHES THICK)
UPPER FREEPORT BED ALLEGANY AND GARRETT COUNTIES
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVELS
LOW VALUES
HIGH VALUES
SYMBOLS
FREQUENCY

Figure H-5
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 80% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

NOT REPRODUCIBLE



MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
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HIGH VALUES
LOW VALUES
MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
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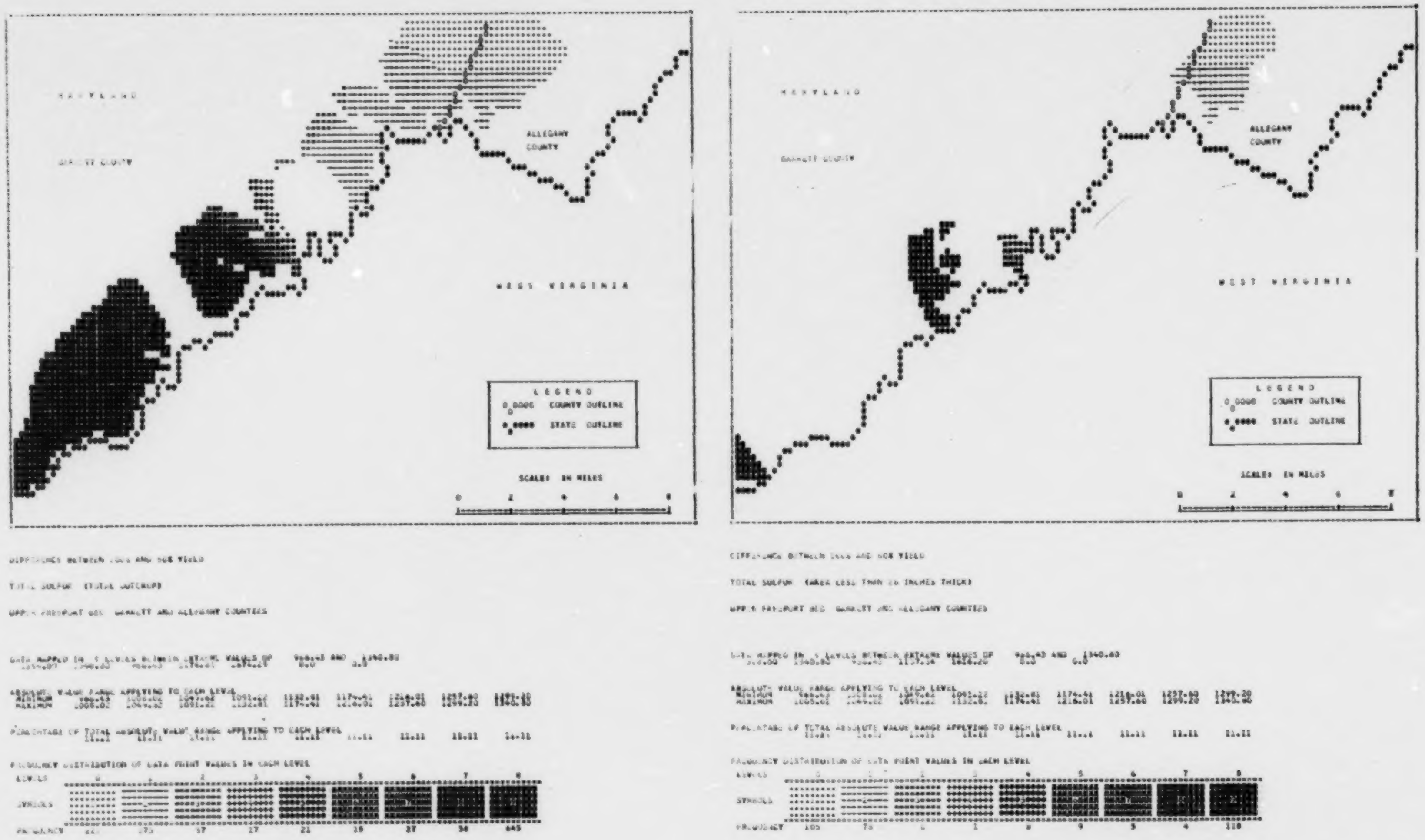
8
HIGH VALUES
LOW VALUES

Figure H-6
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal with less than 1% Sulfur
(100% yield, based on Figure F-3)
left: total outcrop; right: area over 28" thick

NOT REPRODUCIBLE


MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
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COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
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MARYLAND
GARRETT COUNTY
ALLEGANY COUNTY
WEST VIRGINIA
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
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Figure H-7
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal with less than 1% Sulfur
Difference between 100% and 60% yield
left: total outcrop; right: area over 28" thick
(60% yield based on 3/8" mesh total sulfur)

NOT REPRODUCIBLE

## 6. ADDITIONAL DATA CONSIDERATIONS

The study areas for which the computer mapping techniques were demonstrated were selected after reviewing the available analytical, washability and geological data for several possible areas. The criteria for selecting an area for detailed study included: (1) a "reasonable" and "manageable" number of seams, and (2) "adequate" availability of data for each seam for sulfur content, seam thickness and extent, and washability.

In practice any number of seams can be analysed, mapped, and summed to form a composite. The constraints are: (i) preparing base maps and data banks for each seam, (ii) having data points 'adequately' spaced, for each seam, (iii) having a separate computer storage file for each seam, and (iv) having the additional computer budget to prepare maps for each seam. None of these constraints are significantly difficult to fulfill.

The criterion of "adequate" availability of data for each seam for sulfur content, seam thickness and extent, and washability is harder to define. There is no one number that can define the adequacy of data points.

The number of data points necessary for accurate mapping is a function of:

(i) the scale of the map

(ii) the level of detail desired at that scale

(iii) the spacing and clustering of data points, and

(iv) the variability in the surface for the particular variable or phenomenon.

The more variable the surface is for a phenomenon, the greater the number of data points that will be necessary to explain that surface, all else being constant. This can be determined by statistical measures and sampling for each phenomenon as discussed in the following section.

The second section discusses briefly some of the types of data useful for mapping which may often be overlooked, and a means for developing a fuel standard for sulfur oxides depending upon their BTU content.

## 6.1. MAP ACCURACY AND SAMPLING PROCEDURES

A procedure for estimating error can be defined as follows. Suppose we are given a reference surface. We then take a sample of control points from this surface, and contour this sample surface. Next, we lay out a grid (of say 100 points) and produce a second surface. We then take readings from both surfaces. The differences between the test value and the reference value at each of the gridded points are summed, and the mean and standard deviation of the differences are taken. The procedure which minimizes the standard deviation of differences is to be preferred.

Let us then examine the problems of obtaining an accurate sample. First of all, how complex is the surface? Second, what degree of accuracy do we need? And, for this degree of accuracy, what is an economic sampling procedure? Third, given the fact that much information is already available and obtaining new information is costly, what might be a way to minimize new data acquisition costs?

### 6.1.1. Surface Complexity

In an ideal situation, where the reference surface can be shown (such as a topographic surface) one can estimate the complexity of the surface by counting the number of peaks (local maxima), pits (local minima), passes, and pales (points where ridge lines and course lines intersect). Roughly speaking, two times the number of peaks plus pits equals the total number of critical points. (Warntz, 1967, p. 56).

Shepard (1970) points out an interesting mathematical relationship for the distribution of errors between a sample surface and a reference surface, using an aligned stratified (checkerboard) sample:

$$S = k\ (N)^{-1/2}$$

--Where S = standard deviation,

--N = number of points, and

--K = a constant, equal to about 2 standard deviations from the original reference surface.

Thus, the rate of decrease of the standard deviation drops half as fast as the rate of increase of the number of points.

There are diminishing returns associated with increasing the number of points even when this sampling design is used. Thus, if the surface has a great deal of detail and knowledge of this detail is crucial to the investigator, then many points will be necessary to adequately represent the surface.

How many points should there be? Let us assume a surface with a great deal of variability. At a small scale (for instance, a state or group of states) a detailed map of the surface is not necessary. Here the objective is to obtain a rough idea of regions which might be more intensively investigated at a later date. The interpolated values of sulfur content are not to be taken literally, as the distance between points may be several miles.

At a county scale, the goal again may be simply to delineate promising areas, and perhaps to estimate reserves. At the scale of a topographic sheet (one inch to a mile) the emphasis may well be to estimate reserves, and here a more systematic sample should be made. Finally at the largest scale, when working within a mine or adjacent mines, the operator would need a fine-grained sampling method to pick out the coals with varying quantities of sulfur for a working map.

How can we define an efficient sampling procedure for several successive scales?

### 6.1.2. Hierarchial Sampling

Sulfur content of coal has great variability, vertically within a bed as well as geographically. (Gluskoter and Simon, 1968, p. 15-17). The question of confidence in the estimates of sulfur content interpolated from the data points is a problem which depends on the scale of investigation as well as the variation in the data utility. Olson and Potter (1954) suggest a hierarchial sampling design to study crossbedding in a formation. Hierarchial sampling is done at several scales.

In essence, the hierarchial case of the analysis of variance estimates the amount of variability at each level of subsampling. Potter and Siever have also applied this approach to cross-bedding analysis (1955) and to stratigraphic variability (1956). Krumbein and Slack (1956) have examined the radioactivity of a shale. The sampling procedures in these studies are particularly instructive for the problems at hand. Reference in the literature is also made to Cochran, Mosteller and Tukey (1954), who have written an article on sampling principles.

Krumbein and Slack's study of a shale in the Brereton cyclothem in Illinois may serve as a useful hierarchial sampling model for our investigations. They note that widely spaced samples are necessary to discern regional differences in radio-activity in the shale while closely spaced samples are necessary for local detail. Thus, Krumbein and Slack divided their large area into 11 master units, of 3x3 townships. Two townships were randomly selected from each super-township, and four samples were selected from each mine. The regional design has four levels. They then sampled within each mine on a five level hierarchy to determine the variability of samples within the mine. Once the analyses of the variability were made it was determined that regional maps of the shale radioactivity may be based either on mines or on townships as appropriate sampling levels.

Several working maps were prepared by using (1) the average of 16 sample values in each supertownship, (2) the average of 8 sample values in each sampled township, (3) the average of 4 sample values from each mine. The maps became progressively more detailed as the scale increased.

Suppose we are to make a thorough systematic study of a small region (such as a coal mine) to reveal the fine details of the sulfur distribution. Berry and Baker (1968) suggest after review of several techniques, that a stratified systematic unaligned sample is to be preferred for the most accurate sampling results when the nature of the non-randomness of the data is unknown. With this procedure, a square grid is imposed on the map and a point is selected at random with respect to the x and y coordinates in the upper left hand corner of the grid. This point will be called R1C1 for row one, column one.

The x coordinate of R1C1 is then used with a new random y coordinate to locate R1C2 and so on across the top row of strata (grid cells). By a similar process, the y coordinate of R1C1 is used in combination with random x coordinates to locate point R2C1 and all successive points in the first column of strata. The random x coordinate of each row and random y coordinate of each column are used to locate all other points until all cells have sample elements.

The resulting sample combines the advantages of randomization and stratification with the useful aspects of systematic samples, while avoiding the possibility of bias because of the presence of periodicities. (Berry and Baker, 1968, p. 93; see Fig. 4).

Since a stratified hierarchial sampling procedure may have varying densities of data points, the map reader should be cautious about his interpretations. There is a tendency to place more confidence in a map than is justified by the geographic coverage of data points and by the variability of the data.

### 6.1.3. Sampling in Current Practice

While the hierarchial sample is presented as a good model, its complete application to coal mapping may not be appropriate. First of all, much information has already been gathered, without regard to the niceties of random geographical coordinates. Secondly, a knowledge of the geology may lead to drilling new core samples in areas which the suggested sampling procedures may well avoid. Nonetheless, the hierarchial design is useful, and, in the absence of a strong reason based on geological knowledge, some random selection of new data points is advisable.

How can we evaluate the existing pattern of coal sampling points of a region to know whether the maps to be made have a reasonable chance of being accurate? Morrison (1970) suggests an answer. Morrison tested several sampling designs, and found measures of accuracy for each. He then calculated the nearest neighbor statistic for the sample points (this is a measure of dispersion) and found that the accuracy was proportional to the value of the nearest neighbor statistic:

$$R_n = \frac{Dobs}{.50(A/N)} - 1/2$$

where

--$R_n$ is the nearest neighbor statistic,

--Dobs, is the observed mean distance between points and their nearest neighbors,

--A is the area, and

--N is the number of points.

The values of $R_n$ range from zero (where all the points are clustered together at one place), through 2.1491 (where the points are as far as possible from each other and therefore form a regular hexagonal distribution )

Morrison (1970, p. 501) states that if the nearest neighbor statistic is less than .90, the map will not be accurate. If the statistic exceeds 1.25, the map will be more accurate than if the value is less than 1.25. Apparently 1.25 was selected as a conservative break point, since the mean of 2,15 is 1.075. We can improve our knowledge of an area by filling in unknown regions where sample points are missing, perhaps with some uniform grid and random coordinates, until the nearest neighbor statistic increases above 1.25.

Nearest neighbor measures are relative; they show the relative dispersion for various arrangements of N points over an area. If the region is almost featureless, then only a few sample points--if they are well dispersed--can give a proper picture of the original surface. If the surface is complex, more points are needed. If the purpose for which the map is made is not critically dependent on showing fine detail, then fewer points may be needed.

### 6.1.4. The Interpolation Algorithm

A classic problem in interpolation can be illustrated in this fashion:

3. .24

Where do we draw the "10" contour?

27. .8

When the data points are located on a rectangle or square situations such as these can occur. When the data points are located on an hexagonal lattice the contours can be unambiguously drawn.

In practice, cartographers look to surrounding areas for clues about slopes, maxima and minima, and perhaps ridge and course lines. The interpolation algorithm used in SYMAP and designed by Donald Shepard, does the same thing. The program searches nearby points and estimates a most likely value. The weighting is done on the basis of distance and direction of data points, and degree of slope to these data points.*

One can have confidence in SYMAP's interpolation program. We note that the solutions it produces are unique; this would not be true in every case if several map makers made interpolations on the same complex surface.

The computation part of the program takes as given the coordinates of one or more "data points" and the values associated with them. Unless otherwise specified, the surface is smooth (continuously differentiable), passes through the given points, and represents trends or patterns which those points imply. The method of calculation is a weighted average of slopes and values of nearby data points, developed from a gravity-type model.

For efficiency, the procedure is normally used to calculate the values only at grid points--every third character location across and every other down. The intermediate points are evaluated by a quick linear interpolation between the grid points. For accuracy, all values are computed as decimal (floating point) numbers and converted to levels and symbols just before printing.

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*See the report on the SYMAP Interpolation Algorithm", Computer Mapping as an aid in Air Pollution Studies, Volume Two, Report L; Laboratory for Computer Graphics and Spatial Analysis, April 1970

The interpolation algorithm gives characteristic effects when extrapolating beyond the study area. As the distance increases, all the nearest data points have roughly the same distance and direction, resulting in approximately equal weightings. Thus, the values will tend towards a limit near the average of the closest data points.

In interpreting a SYMAP, one should recognize that it is *perfectly* reliable--up to the accuracy of the data--*only* at data points. Where the spacing of data points is relatively wide, or where the data value fluctuates rapidly from one data point to its neighbors, the SYMAP is less reliable and is best interpreted as a general picture. Only if the user is confident that his spacing of data points is *finer* than the scale of the phenomenon he is mapping, may he confidently assume that a SYMAP--like any contour map based only on those data--is valid.

## 6.2. SPECIAL CONSIDERATIONS IN DATA ACQUISITION

### 6.2.1. Types of Data for Mapping

One of our tasks is to map coal which varies in quality and quantity. First of all, coal varies in thickness from place to place and from seam to seam. The area underlain by coals also varies. In addition, the coal varies in BTU content, ash, fixed sulfur and organic sulfur, volatile matter and moisture. Furthermore, coals respond differently to crushing. In general crushing helps remove sulfur and ash. However, this is not always true in the case of sulfur. Finally, coals are subjected to gravity sorting, and this may have marked effects on sulfur and ash content.

Information, therefore, is needed covering the following types of data and analyses:

1) The areal extent of each seam in the area being investigated.

2) The vertical location of the seam, below the surface and above sea level.

3) The precise sampling point location, and the thickness of the seam at each sampling point.

4) For each sampling point the raw coal will be analyzed. Calculations seem most useful if they are based on an as-received basis. The coal will be crushed to various sizes and will be analyzed at these sizes. For each size there will be the following analysis:

   a) Percent yield
   b) Percent sulfur
   c) Percent ash
   d) BTU content.

Next, the difference between two grades of crushing can be calculated, so that changes in the yield, sulfur and ash content can be evaluated.

5) Float and sink data for each location. Cumulative float and sink data reflect the percent ash and percent sulfur for remaining fractions of the coal which have a specific gravity lower than a given level. The specific gravity curve tells what percent of the coal sample has a specific gravity less than a given level. This gives percent yield of coal after a given gravity separation. The specific gravity distribution curve of ± 10 percent tells how easily and exactly separation can be made at various values of specific gravity.

Coe (1938) has written a thorough explanation of the washability curves. Coe states that the cumulative ash (or cumulative sulfur) curve when drawn by hand, and without knowledge of the elementary ash (or sulfur) curve, can be in error. Coe points out that the elementary curve is the first derivative of the cumulative curve. The cumulative curve, when improperly drawn, will give an unsmooth elementary curve. While Coe suggests a laborious checking procedure, it seems as though a computer could generate the best fitting cumulative curve so that the first derivative elementary curve would not show rapid changes in slope.

Given that the proper subroutine could be placed in the general program, cumulative curves for ash and sulfur could be calculated, as well as specific gravity and the ± 10 percent specific gravity curves. Interpolations of values on the cumulative curves could then be evaluated from the standpoint of technical and economic feasibility.

## 6.2.2. Sulfur Oxide/BTU Fuel Standard

A more general and more accurate fuel standard to measure sulfur content can be examined in relation to the BTU content of the fuel. Coal has been classified in many ways (Rose, 1945). It is generally classified by rank and this rank is correlated with BTU content, (Rose, 1945, p. 59) Since sulfur cannot be correlated with rank or BTU content,* it follows that a classification is needed to distinguish high from low sulfur coals of comparable heating ability.

For the purposes of this discussion, we will consider the coal on an as-received basis, after crushing and cleaning. We will not consider other measures of BTU content,** such as moisture free, moisture and ash free, H value, or moist mineral matter free, because we are interested in a comparison of coals delivered for consumption. (Barkley and Burdick 1941, p. 2)

In current practice, the amount of sulfur dioxide generated per ton of coal is calculated by multiplying the percent sulfur content by 38. (Duprey, 1968, p. 5).

$$(38)\ S\ (\text{percent}) = SO_2 \text{ in lbs/ton.}$$

This assumes that 5 percent of the sulfur remains in the ash***. The number of BTU s released per ton of coal burned is $26X10^6 \frac{BTU}{Ton}$. This implies a BTU content of 13000 BTU/lb. (Duprey, 1968, p. 5)

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*Mr. S. J. Areaso of the Bureau of Mines in a letter dated April 12, 1971 to Mr. R. C. Campbell, of the Air Pollution Control Office, Office of Program Development.

**Rose (1945, p. 56) points out that direct BTU determination with a calorimeter is easy, and accurate.

***US Dept HEW, Report AP 52, 1969, Chapter 7, p. 2; a complete review of alternatives in standards, in the technology of burning, and substitutability of fuels, may be found in this report.

Since coals vary in rank (BTU content) a more accurate index of the sulfur pollution potential of a coal is made by creating a ratio between $SO_2$ in lbs per ton/BTU per ton. Hence

$$\frac{38 \quad S\text{ (in percent)}}{2000\,\frac{\text{lbs}}{\text{ton}} \;\cdot\; \frac{\text{BTU}}{\text{lb}}} = \frac{\text{lbs } SO_2/\text{ton}}{\text{BTU / ton}} = \frac{\text{lbs } SO_2}{\text{BTU}}$$

This index (or one of similar construction in current use) could be usefully mapped to outline the comparative sulfur pollution potential of coals of varying ranks.

It should be recognized that other attributes of the coal, such as ash content and the fuseability, etc., are important characteristics which can also be mapped and which have an effect on the potential market for these coals.

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## 7. DATA HANDLING ROUTINES

Several useful data handling routines were developed in the course of the study area analyses and mapping.* Two of these are discussed in the following sections: (1) the use of Subroutine MANIP with SYMAP, and (2) techniques for displaying the number of analyses as legends.

### 7.1. SUBROUTINE MANIP WITH SYMAP

In one series of maps for the study area the sulfur content data were aggregated and mapped by counties; in a second series of maps, the data were aggregated and mapped by towns. The surfaces resulting from these two data aggregation procedures were compared to determine what scale of aggregation would be most useful, in relation to the time involved in obtaining and manipulating the data.

To compare the two surfaces directly in one submission with the SYMAP program required the writing of a new subroutine entitled Subroutine MANIP. MANIP is called by the normal user subroutine, FLEXIN. The parameters to be specified are clearly spelled out in comment statements contained in subroutine FLEXIN; these include the size and form of the surfaces to be compared, the desired size and form of the output map, and the spacing of the grid on which the comparison will be made. Subroutine FLEXIN as used with Subroutine MANIP is shown in Figure 6.

This Subroutine FLEXIN was used to produce maps D-1 and D-2. The maps for the mode value of sulfur content

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*The important program modifications essential to the mapping techniques are presented in section 8 of part 2, Computer Program Manuals.

```
      SUBROUTINE FLEXIN (IFORM,T,FIRST)
      DIMENSION T(2)
      LOGICAL FIRST
      GO TO (31,40,32,40),IFORM
   31 CONTINUE
      IF (FIRST) CALL MANIP(5,4,1,12,11,77.7,16.0,0.0,0.0,0)
C***********************************************************************
C*    ARGUMENTS - IGRIDX,IGRIDY,MAPNO,ITP,ITPSKR,XYBASE,XYMAP          *
C*       YOMAP,XOMAP,IBACK.                                            *
C*    IGRIDX = ACROSS, IGRIDY = DOWN GRID SPACING FOR CALCULATING FROM *
C*       MAP ON UNIT 8. 1/2 INCH GRID IS 5 X 4, USE 1 X 1 FOR GRID     *
C*    MAPNO = NUMBER OF OUTPUT MAP USING SUBROUTINE - IF ONLY MAP, 0   *
C*       IF FIRST OR OTHER MAP, 1-8, IF LAST MAP, 9.                   *
C*    ITP = UNIT NUMBER OF OUTPUT MAP, USUALLY 12.                     *
C*    ITPSKR = UNIT NUMBER OF SUBROUTINE SCRATCH TAPE, USUALLY 11.     *
C*    XYBASE = X OR Y DIMENSION OF BASE MAP, IN SOURCE UNITS           *
C*    XYMAP = CORRESPONDING DIMENSION OF MAP ON UNIT 8, IN MAP INCHES  *
C*    YOMAP AND XOMAP = X AND Y DISPLACEMENT OF MAP ON UNIT 8 FROM 0-0 *
C*    IBACK = 0 STANDARD. IF > 0, WILL WRITE OUT BACKGROUND CELLS AS   *
C*       INPUT TO GRID PROGRAM.                                        *
C***********************************************************************
      READ(12) ITEST,T(2),T(1)
      IF(ITEST.EQ.99999) IFORM=99999
      RETURN
   32 CONTINUE
      IF(FIRST) CALL MANIP(5,4,9,12,11,77.7,16.0,0.0,0.0,0)
      READ(12) ITEST,T(2),T(1)
      IF(ITEST.EQ.99999) IFORM=99999
      RETURN
   40 CONTINUE
      IF(FIRST) REWIND 12
      READ(12) ITEST,X,Y,V1,V2
      IF(ITEST.EQ.99999) IFORM=99999
      T(1)= V1-V2
      RETURN
      END
```

FIGURE 6
FLEXIN with Subroutine MANIP

(both raw and washed) by county and by town (maps A-3, A-7, B-3, and B-10) were run and the values for each character cell stored on disk. These values were read in and the two surfaces compared at locations on a grid defined as arguments to MANIP in Subroutine FLEXIN; maps A-3 and B-3 were compared first to produce D-1 and A-7 and B-10 second to produce D-2. Read statements 31 and 32 refer to the data points for maps D-1 and D-2 respectively, and READ statement 40 to the values to be mapped.

The same outline and legend packages were used as in the original maps; the data point and values packages were created internally by the program. The F-MAP package employed different electives for minimum and maximum values, number of levels, value range intervals, and symbolism.

Each of the variables passed between MANIP and FLEXIN is discussed in comment statements in FLEXIN and in more detail below:

--IGRIDX and IGRIDY--the maps stored on disk (A-3, A-7 B-3, and B-10) may not always be at the same size as the source map, or the output map desired. These variables select the spacing of cells for comparison at the scale of the maps stored on disk; 5x4 grid was used for maps D-1 and D-2.

--MAPNO--defines which call to MANIP is being exercised so as to have the correct rewinding of disk files.

--ITP, ITPSKR--the maps stored on disk are on unit 8, usually on successive files. If this is not the case then MAPNO should be changed accordingly; the first file is read only for the 'first' map as specified by MAPNO. ITP is the output unit which is read elsewhere in Subroutine

FLEXIN, and ITPSKR is any scratch unit, used in MANIP for temporary storage of the first map while the second is read in. If the two surfaces to be compared are not on the same unit, then several changes would be necessary in MANIP:

(i) specify another unit for reading in variable V2;

(ii) read in V1 and V2 concurrently and compare: this eliminates need for ITPSKR.

(iii) make necessary changes in FLEXIN calling arguments if desired.

--XYBASE, XYMAP--if maps stored on disk are not at the scale of the base map, then the corresponding x or y dimensions of the base map (in source units) and the stored map (in inches) should be specified here. If they are at the same scale, the number "1" should be specified for both variables.

--YOMAP, XOMAP--if maps stored on disk did not start from the origin in the upper left-hand corner, then the y and x displacements should be specified in source units. If the maps did start at the origin, "0" should be specified for both variables. XYBASE, XYMAP, YOMAP, AND XOMAP are used to ensure that the output map has coordinates in source map units with the correct orientation to the origin, no matter what scale--and for what portion of the study area--the maps stored on disk were produced. In this way all map electives and FLEXIN manipulations can be specified as usual, in relation to the source units.

--IBACK--Subroutine MANIP can be used to create values for mapping with the GRID program, by making minor changes in Subroutine FLEXIN. IBACK is used to code cells outside the outline with the GRID background value, -999999.0; if the GRID program is not to be used, then IBACK should be set equal to "0".

As used for the study area mapping, Subroutine MANIP immediately followed Subroutine FLEXIN. If it were to be used as a standard procedure, it should be compiled together with all the other non-user subroutines. This was not done here, since the core requirements (200 K) are greater with this subroutine than with normal submissions.

Figure 7 shows the complete subroutine as used in this project. Some of the more important aspects--referenced by line number--are briefly discussed below:

| line number | description |
|---|---|
| 8 | Maps are stored on disk, one record per row. KSNK controls the number of records to be skipped when reading, in relation to the grid size (in the y direction) for map comparison. |
| 13 | The maximum number of words (one word for each column of the map) written by SYMAP onto the file is 130 per record. Therefore, if the map stored is greater than 13" wide (130 columns), all rows for the first 130 columns will be written first, followed by all rows for the remaining columns. The file must be read back the same way. |
| 16 thru 23 | Reads past unwanted records; reads desired row, assigning each column--up to the first 130--to V1(J), and writes out same data. |
| 24 thru 35 | Checks to see if last row; if greater than 130 columns, goes back and reads in remaining data. |
| 44 thru 47 | Sets grid spacing in x direction, checking to see if greater than 130 columns. |
| 54 thru 56 | Reads in variables for 1st map (stored on ITPSKR) and variables for 2nd map simultaneously, in same manner as 16 thru 23 above. |

```
      SUBROUTINE MANIP(IGRIDX,IGRIDY,MAPNO,ITP,ITPSKR,XYBASE,XYMAP,
     1 YOMAP,XOMAP,IBACK)
      DIMENSION V1(500),V2(500),IV2(500)
      EQUIVALENCE (V2(1),IV2(1))
      REWIND ITP
      REWIND ITPSKR
      IF(MAPNO.EQ.0.OR.MAPNO.EQ.1) REWIND 8
      BACKGR=-999999.0
      KSNK=IGRIDY-1
      I=1
      ITEST=0
      READ (8) ITOT,JTOT
      JKT=JTCT
      IF(JTOT.GT.130) JKT=130
      JIN=1
  300 CONTINUE
      IF(KSNK.EQ.0) GO TO 101
      DO 100 K=1,KSNK
      READ(8) SINK
      I=I+1
  100 CONTINUE
  101 CONTINUE
      READ(8) (V1(J),J=JIN,JKT)
      WRITE(ITPSKR) (V1(J),J=JIN,JKT)
      I=I+1
      IF((I+KSNK).LE.ITOT) GO TO 300
      IF(JKT.EG.JTOT) GC TO 130
      IF(I.GE.ITCT) GO TO 111
      DO 110 K=I,ITOT
      READ(8) SINK
  110 CONTINUE
  111 CONTINUE
      JIN=JKT+1
      JKT=JTCT
      I=1
      GO TO 300
```

NOT REPRODUCIBLE

FIGURE 7
Subroutine MANIP

```
  130 CONTINUE
      READ(8,END=140) SINK
      GO TO 130
  140 CONTINUE
      I=1
      REWIND ITPSKR
      READ(8) SINK
      JIN=1
      JKIX=IGRIDX
      JKT=JTOT
      IF(JTOT.GT.130) JKT=130
      JKFX=(JKT/IGRIDX)*IGRIDX
  310 CONTINUE
      IF(KSNK.EQ.0) GO TO 151
      DO 150 K=1,KSNK
      READ(8) SINK
      I=I+1
  150 CONTINUE
  151 CONTINUE
      READ(8) (V2(J),J=JIN,JKT)
      READ(ITPSKR) (V1(J),J=JIN,JKT)
      I=I+1
      Y=I
      Y=(Y-1.)/8.
      Y=(Y*XYBASE/XYMAP)+YOMAP
      DO 200 J=JKIX,JKFX,IGRIDX
      IF(IV2(J).EQ.25) GO TO 199
      X=J
      X=X/10.
C
      X=(X*XYBASE/XYMAP)+XOMAP
      WRITE(ITP) ITEST,X,Y,V1(J),V2(J)
      GO TO 200
  199 IF(IBACK.GT.0) WRITE (ITP) ITEST,X,Y,BACKGR,BACKGR
  200 CONTINUE
      IF((I+KSNK).LE.ITOT) GO TO 310
      IF(JKT.EQ.JTOT) GO TO 230
      IF(I.GE.ITOT) GO TO 211
```

NOT REPRODUCIBLE

FIGURE 7 Contd

```
      DO 210 K=I,ITOT
      READ(8) SINK
210   CONTINUE
211   CONTINUE
      JIN=JKT+1
      JKT=JTOT
      I=1
      JKIX=JKFX + IGRIDX
      JKFX=(JTOT/IGRIDX)*IGRIDX
      GO TO 310
230   CONTINUE
      READ(8,END=240) SINK
      GO TO 230
240   CONTINUE
      ITEST=99999
      A=0.0
      WRITE(ITP) ITEST,A,A,A,A
      END FILE ITP
      REWIND ITP
      IF(MAPNO.EQ.0.OR.MAPNO.EQ.9) REWIND 8
      REWIND ITPSKR
      RETURN
      END
```

FIGURE 7 Contd

| line number | description |
|---|---|
| 58 thru 60 | Sets output y axis, taking into account scale and extent of input maps. |
| 61 thru 70<br>(62 and 69) | Calculates x axis, as above. Checks to see if cell is outside study area (coded by integer "25" in SYMAP); if so, assigns background value. ITEST is a dummy variable as used here. |
| 71 thru 83 | Checks to see if greater than 130 columns; if so, resets x axis increment and repeats for remaining columns. |
| 88 thru 90 | Normally, when SYMAP reads in packages such as B-DATA POINTS or E-VALUES, the number of calls to FLEXIN (or data points) must be specified. As an alternative when IFORM is set equal to 99999, this is recognized as the last call to FLEXIN. ITEST is set equal to 99999 for the last data point; FLEXIN then sets IFORM = 99999 when it encounters ITEST = 99999. |

Note that the values for both surfaces are read in by FLEXIN from unit 12. Therefore, the user has control in FLEXIN over the surface manipulations and comparisons.

## 7.2. DISPLAYING NUMBER OF ANALYSES

The data banks of sulfur content used for the study area generally contained four variables: the low, mode, and high value for sulfur content, and the number of analyses on which these values were based. On the base maps for the study area in Phase I and II the data points, outlines, and legends are displayed, but no values are shown. We wished to display the number of analyses adjacent to each data point to aid in the evaluation of the accuracy of the data for various parts of the study area.

The number of analyses for each data point can be displayed on the base map as a point C-OTOLEGEND. A small data handling program was written to produce a punched deck of C-OTOLEGENDS. This is shown in Figure 8 and discussed below with reference made to the line numbers:

| line number | description |
|---|---|
| 2 thru 4 | The number of legends packages to be created this run (number of different base maps). |
| 6 | Read in the data point locations. |
| 7 thru 9 | Transform these if the source map units used for data points and legends are different. |
| 11 | Check to see if all points have been read in. |
| 17 thru 19 | Read in the corresponding values for the number of analyses at each data point. |
| 20 thru 27 | Punch out cards in the standard C-OTOLEGENDS format, including a vertical and horizontal displacement of one print character from the data point. |

Figure 8 also shows a listing of some of the legends punched out by this program.

```
      DIMENSION Y(500),X(500)
      READ(5,99) NTIME
   99 FORMAT(I5)
      DO 50 K=1,NTIME
      I=1
   10 READ(5,100) KNT,Y(I),X(I)
      IF(K.LT.3) GO TO 15
      Y(I)=(626.-Y(I))/6.37
      X(I)=(X(I)-322.)/6.37
   15 CONTINUE
      IF(KNT.EQ.99999) GO TO 20
      I=I+1
      GO TO 10
  100 FORMAT(I5,5X,2F10.2)
   20 CONTINUE
      KNT=I-1
      DO 30 J=1,KNT
      READ(5,200) IV
  200 FORMAT(I4)
      NUM=4
      VDISP=-1.0
      HDISP=-1.0
      WRITE(7,300) NUM,Y(J),X(J),VDISP,HDISP,IV
      WRITE(6,301) NUM,Y(J),X(J),VDISP,HDISP,IV
  300 FORMAT(4X,I1,4X,1HP,4F10.2/I4)
  301 FORMAT     (4X,I1,4X,1HP,4F10.2,30X,I4)
   30 CONTINUE
   50 CONTINUE
      STOP
      END
    4    P     42.15     53.00     -1.00     -1.00
   1
    4    P     37.21     38.08     -1.00     -1.00
1659
    4    P     29.61     33.27     -1.00     -1.00
  29
    4    P     42.20     43.04     -1.00     -1.00
   5
```

FIGURE 8
Legends for Number of Analyses